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Rapid Stabilization of Thawing Soils for Enhanced Vehicle Mobility

A Field Demonstration Project

Maureen A. Kestler, Sally A. Shoop, Karen S. Henry, Jeffrey A. Stark, and Rosa T. Affleck

February 1999

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Cover: Stabilizing surfaces being trafficked by the Heavy Expanded Mobility Tactical Truck (HEMTT).

CRREL Report 99-3

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13. ABSTRACT (*Maximum 200 words*)

Thawing soil presents a formidable challenge for vehicle operations cross-country and on unsurfaced roads. To mitigate the problem, a variety of stabilization techniques were evaluated for their suitability for rapid employment to enhance military vehicle operations. A combination of mechanical stabilization methods including several lightweight fills, geosynthetics, and tire and wood mats, were constructed and tested during the annual training exercises of the 229th Engineers of the Wisconsin National Guard during the difficult conditions of spring thaw. The techniques were evaluated for their expediency, ease of construction, trafficability, and durability. In general, chunkwood was an excellent replacement for gravel fill in forested area; tree slash (or other vegetation) was effective but labor intensive; wood mats and pallets were effective and reasonably durable; tire mats were extremely rugged and effective. A loader or crane was needed to place the large wood mats, tire mats, and fascines. Geocomposite materials (Geonet) were quickly installed and could withstand limited traffic (50 passes) without additional cover material. Geosynthetics reduced the amount of cover material and enhanced placement, effectiveness and removal when used under other materials to spread the load and keep them from sinking into the mud. All materials were damaged during the severe motion of a tank cornering except the large, smooth wood mats, but these were slippery on slopes. Results are summarized in a decision matrix for choosing the best technique depending on site conditions, material and equipment availability, and utilization criteria.

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PREFACE

This report was prepared by Maureen A. Kestler, Research Civil Engineer , Civil Engineering Research Division, Sally A. Shoop, Research Civil Engineer, Applied Research Division, Karen S. Henry, Research Civil Engineer, Jeffrey A. Stark, Research Civil Engineer, and Rosa T. Affleck, Research Civil Engineer, Civil Engineering Research Division, U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), Hanover, New Hampshire. Funding for this work was provided by DA Project 4A762784AT42, CS-M08, *Mobility Models for Thawing Soils (and Wisconsin Experiment)*, and DA Project 40263734T08, DT08-74-101, *Countermobility and Survivability*. Technical reviewers of this report were Randy Hill, Lola Hislop, and Donald Purinton.

The authors thank all who contributed toward the success of the 1995 Expedient Surfacing Stabilization Techniques Demonstration at Fort McCoy, Wisconsin. This demonstration project was the culmination of a 2-1/2-year rapid stabilization study conducted largely in conjunction with, and as the U.S. Army's continuation of, the USDA Forest Service's Portable Wetland Crossing Study. We particularly thank Lola Hislop whose extensive work in portable crossings for unstable soils provided a solid foundation for CRREL's Rapid Stabilization Project to build upon and extend to tank trafficking. Her cooperation and assistance in the development of CRREL's demonstration project are greatly appreciated. We thank James Kerkman (Fort McCoy) for not only providing a site but also for the endless hours he invested into associated arrangements and preparations during the preceding year. We thank SFC Donald Purinton (U.S. Army Engineer School), Lt. Paul Liethen and the 229th Engineer CSE Co. of Wisconsin National Guard, David L'Heureux and Randy Hill (CRREL), Robert Radcliffe, Joseph Sturos, and James Mattson (Forestry Products Lab, North Central Experiment Station, USDA Forest Service), William Foster (Osceola National Forest, USDA Forest Service), Steve Webster (Waterways Experiment Station), Rodger Arola and John Bowman (USDA Forest Service retirees), Candy Thornton (Fort McCoy), Jerry Goldberg (Terra Mat Corp.), and Joseph Pouyer (Uni-Mat International, Inc.) for their many contributions to the cooperative demonstration project.

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A Field Demonstration Project

MAUREEN A. KESTLER, SALLY A. SHOOP, KAREN S. HENRY, JEFFREY A. STARK, AND ROSA T. AFFLECK

INTRODUCTION/BACKGROUND

Thawing soils can create very difficult conditions for vehicle movement both on trails and off-road. Frozen substrate prevents drainage, trapping liquid water in the surface layer of thawing ground. Additional moisture added by thawing frost lenses, snowmelt, and rain can make the thawed layer saturated or supersaturated and unable to support vehicles and equipment. If vehicle passage is possible, the resulting soil disturbance may cause severe environmental damage by rutting, tearing of plant roots, and subsequent erosion problems. Vehicle mobility can be enhanced and environmental damage prevented by appropriate stabilization of thawing ground. Rapid stabilization techniques for thawing soils are critical for successful maneuver of ground forces and sustainment operations. An initial review of rapid mechanical stabilization techniques is given in Kestler et al. (1994). The objective of this project was to evaluate the construction and performance of the stabilization methods for military use (maintaining lines of communications, transport and support functions, and combat trails) on thawing ground.

This report describes the stabilization techniques and their field evaluation. A resulting evaluation matrix was developed based on the reported results to aid in decision making. Although the field evaluation was performed with military vehicles, the stabilization techniques are suitable for many civilian applications, such as for construction, mining, petroleum exploration, and forestry, where the ability to travel on thawing ground is desirable.

Rapid stabilization techniques were tested in three configurations: sloped sections with a 16 to 18% grade, a pentagonal loop trail to test cornering, and the largest experiment, a thawing wooded trail. The stabilization techniques used the following materials both alone and in combination: chunkwood, tire chips, wood mats, tire mats, fascines, tree slash, geosynthetics, and gravel. There was minimal trail preparation prior to placing the materials. Details such as labor and equipment needs, time, and amount of material for construction of each surface were carefully observed and noted. Prior to construction, the terrain and soil were characterized. After the test sections were completed, the trail was trafficked with wheeled and tracked vehicles. During trafficking, both the vehicle performance and test surface performance were monitored for surface damage through rutting and lateral expansion, material interference with vehicles, ride quality, vehicle traction and handling problems.

This field evaluation was a collaborative effort among several government organizations and private industry. The USDA Forest Service (USFS), interested in environmentally friendly forest operations, assisted in the production of chunk-

wood, which can be used as a wear surface or base course for roads and trails. The U.S. Army Engineer School helped with planning and executing the test and evaluation program to assess various techniques for military use. The 229th Engineer SCE Co. of the Wisconsin National Guard constructed the trails as well as performed the trafficking and evaluation as part of their annual training exercise, which is described in the *Mission Statement* (App. F). Two private companies, Terra Mat Corporation and Uni-Mat International, Inc., donated their time and materials to have their products evaluated for military use. For CRREL, it was an opportunity to work directly with our military customer, incorporating feedback on construction and performance into our evaluation and providing excellent field data on the mobility of military vehicles on thawing ground. This type of interaction is essential for developing military engineering and combat models for simulations, as well as new methods and materials for military applications.

STABILIZATION TECHNIQUES

The following stabilization techniques were chosen for field evaluation based on their applicability to military use, expediency, ease of construction, and their mechanical interaction with thawing ground to distribute loads and provide vehicle traction. The type of stabilization materials used and their placement in the field are listed in Table 1 and are described subsequently.

Table 1. Summary of stabilization techniques tested.

	Test location				
Stabilization technique	*Wooded trail*	*Slopes*	*Corner*	*Pretest*	*Test conditions*
Chunkwood	X	X	X		20 to 40 cm (8- to 16-in.-) thick test sections added in NOGO situation (see App. H)
Tire mats (Terra Mat)	X	X	X		
Hand-assembled wood pallets	X	X			
Commercial wood mats (Uni-Mat)	X	X			
PVC fascine	X				Covered with chunkwood, tire mats and wood mats
Tire chips	X	X	X	X	
Slash	X	X	X		
Geotextiles					
a) Double-sided geonet	X	X		X	Bare
b) Polypropylene (TS 1000) with 10- to 30-cm (8- to 15-in.) gravel cover	X		X	X	
c) Polypropylene (TS 1000) with chunkwood, tire chips and slash cover	X				
d) Woven slit film polypropylene	X			X	Wooded trail—used to wrap wrap chunkwood for lateral confinement
e) Geogrid				X	
f) Nonwoven polyester (Trevera)	X			X	0- to 13-cm (5-in.) gravel cover on wooded trail
g) Polypropylene-reinforced with polyester fibers (Polyrock)	X	X		X	Bare
Gravel (conventional road)	X				Gravel added in NOGO situations after chunkwood was used up

Chunkwood

Chunkwood is a product developed by the USFS as a replacement for granular material. It is produced by chopping trees in a "chunker," a large shredder that cuts trees into particle sizes ranging from a few centimeters to 20 cm (8 in.), depending upon the diameter of the trees put into the machine. The wide range in sizes of the angularly shaped wood promotes particle interlock. High permeability makes chunkwood a good replacement for gravel in wet areas. It also biodegrades slowly. Some chunkwood roads had been in place with no improvements to them for over 8 years (Arola et al. 1991). Chunkwood is typically used as a base course. However, for expediency, no cover was placed on the chunkwood, and it was tested as a wear surface. Chunkwood was mixed with sand to increase the grain size range and improve interlock. Thickness of the chunkwood sections ranged from 20 to 40 cm (8 to 16 in.). In addition to the chunkwood test sections, chunkwood served as the mainstay of the trail improvement program, replacing gravel wherever additional fill was required.

Tire chips

Tire chips are produced by shredding old tires in pieces that will pass through a 5-cm (2-in.) sieve. Although the tire chips were ordered to be cut with fresh blades to reduce the amount of exposed metal, metal pieces protruded from many chips, and tire bead steel was prevalent. Prior to the field demonstration, a small section of tire chips was spread and compacted with a front end loader, and trafficked with a CJ5 to determine if tire damage would be a major problem. The tires of the CJ5 were punctured by the steel after only a few passes, but the larger tires of the front end loader did not suffer, even though some small pieces of steel were stuck in the tire. Later the bead steel caused flat tires on a jeep and grader. Tire chips without bead steel can be produced by removing the bead steel before shredded the tires or reduced by using only automobile tires, which have less bead steel than truck tires.

Like chunkwood, tire chips are very permeable and can replace granular fill material. In recent years, tire chips have been used in road bases because of their high permeability and good insulating properties (to reduce detrimental effects of frost action) and to efficiently recycle old tires (Humphrey and Eaton 1995). Commercially available tire chips can be obtained throughout the United States. The chips used in this project were purchased in Wisconsin. The tire chip test sections were approximately 30 cm (12 in.) thick. As was the case with the chunkwood, traffic was applied directly on the tire chip surface.

Geosynthetics

Several types of geosynthetics, some of which were development products or products newly on the market, were tested in pretests to rank their relative resistance to damage incurred by tank trafficking. Geosynthetics are listed in Tables 2 and 3.

Products that sustained the least amount of damage in the pretest (see App. D) were used during the field demonstration in the stabilized test sections without any cover. These were the double-sided geonet and the nonwoven polyester. An additional geotextile section of polypropylene was used with minimal gravel cover (less than 10 cm [4 in.], primarily in ruts) on the wooded trail and with 30 cm (12 in.) of gravel cover on the pentagonal loop trail test section. It was also used beneath sections of tire chips, chunkwood, and slash on the wooded trail. In these sections the geotextile was used to prevent intermixing of the fine-grained subgrade with the fill material and in construction of chunkwood "pillows" to prevent lateral spreading of the chunkwood. The pillows were 6.5 m (20 ft) long. Prior to the pillow construction, the chunkwood migrated into an adjacent depression. The pillow was constructed by laying out the geotextile (transverse to trail direction), covering it with 30 cm (12 in.) of chunkwood and wrapping the remaining geotextile over the chunkwood. The pillow was then covered with chunkwood as a wear surface.

Tree slash

The slash consisted of branches of trees placed at angles to the direction of travel. The technique is commonly used in Alaska to provide a base for a rock fragment surface course for timber access roads. The best method of placing the slash was to use the trunks to fill in ruts and hollows and to lay branches no bigger than 8 cm (3 in.) in diameter in a herringbone pattern at 45° angles to the direction of travel. More slash was added during trafficking to replenish the existing surface.

Tire mats

The commercially available tire mats are constructed of two layers of truck tire tread perpendicular to each other with a layer of truck tire sidewalls on top. These mats are designed to with-

Table 2. Geotextiles tested in pretests at Fort McCoy for rapid stabilization of thawing soils.

Product name/ construction/mass per unit area (g/m^2)	*AOS (mm)/ sieve no.*	*Typical uses*	*Wide width (WW) tensile strength kN/m (lb/in.)*	*Puncture kN (lb)*	*Burst kPa (psi)*
Trevira 011/550/ NW PET/ 541	0.15/#100	P, R, S	36.0 (205.5) 28.8 (164.7)	0.867 (195)	5382 (780)
Polyfelt TS1000/ NW PP/ 540	0.15/#100	P, R, S	24.5 (140)/ same in both	0.71 (160)	3795 (550)
Linq GTF 300/ W PP (slit film)/ 200	0.60/#30	S/S	31.5 (180)	0.80 (115)	4139 (600)
Polyrock (PP with PET reinforcement) 365	> 0.30	R	100 (570)	Not available	Not available

NW = nonwoven, W = woven, PP= polypropylene, PET= polyester
P = protection, R = reinforcement, S = separation, S/S = separation and stabilization

Table 3. Geogrid and double-sided geonet tested in pretests at Fort McCoy for rapid stabilization of thawing soils.

Product	*Polymer type and coating*	*Mass/unit area g/m^2 (oz/yd^2)*	*Typical application*	*Aperture size mm (in.)*	*WW** tensile strength kN/m (lb/ft)*	*Tensile strength @ 5% strain kN/m (lb/ft)*
Contech 553 (Tensar BX 1300)	PP	247 (7.3)	Reinforcement	MD*: 46 (1.8) XD†: 64 (2.5)	16 (1096)	9.9 (678)
Tensar 1605 with geotextile) Double-sided geonet	HDPE (geonet core) (NW PP with 270 g/m^2 geotextile on geonet core)	2000 (60)	Drainage	MD: 15 (0.6) XD: 7 (0.3)	10 (685), for geonet only	Not available

HDPE = high density polyethelyne, PP = polypropylene
* MD = machine direction
† XD = cross-machine direction
** WW = wide width

stand tracked vehicle travel. The dimensions of the mats are 3.2 m (10.5 ft) long and 1.6 m (5.25 ft) wide. The mats weigh approximately 1000 kg (2200 lb) each and were placed by dragging or towing, or by lifting with the Heavy Expanded Mobility Tactical Truck (HEMTT) crane. Tire mats (model TMC 410-12) used were provided by Terra Mat Corp.

Wood mats

Two types of wood mat were tested. One was similar in design to a shipping pallet. These pallets were constructed on site. They were constructed primarily of soft wood, were relatively lightweight, and could be maneuvered into place manually. The second type of wood mat was on loan from Uni-Mat International, Inc. The Uni-

Mats were made of oak and were placed using loaders or the HEMTT crane.

PVC fascine

A fascine was built from schedule 80 PVC pipes by linking the pipes together with 0.95-cm-(3/8-in.-) diameter cable. (Metal pipes or schedule 40 PVC with a thinner cable can also be used.) The fascine was constructed on site, and was used to fill low-lying areas while still maintaining drainage though the pipes. One fascine mat was covered with tire mats in an area where it filled a small stream, and another was used with geotextile and chunkwood where the trail turned a corner adjacent to a swamp.

Control

Each test area had one or more control sections of bare ground with no stabilization treatment. Gravel or other materials were brought in if "NOGO" situations were encountered.

SITE CHARACTERIZATION TESTING

Table 4 summarizes soil tests conducted and terrain properties measured on the wooded trail, sloped trail, and pentagonal loop trail. Typical data record sheets are shown in Appendix F. Each of the three trails will be described in detail following a brief description of testing and sampling.

Detailed photographic and visual observations were included as part of both site characterization and performance testing.

Laboratory CBR tests

Ten soil samples were taken and sent to CRREL's Soils Laboratory for CBR testing (CBR tests are an index of soil bearing capacity). Compaction tests were conducted using ASTM Standard D 698, Method C, and CBR tests were conducted using ASTM Standard D 1883 (ASTM 1985). Test procedures are outlined and results discussed in Appendix B.

Dynamic cone penetrometer (DCP)

The DCP is a sturdy, portable device that can penetrate soil layers with CBRs ranging from less than 1 to greater than 100 (Webster et al. 1992). Shown in Appendix B (Fig. B5a), it consists of a 16-mm- (0.625-in.-) diam. steel rod with a 60° cone of base diameter 20 mm (0.790 in.) attached to one end. The cone is driven into the ground by a sliding hammer, and penetration and corresponding blow count are recorded until resistance, or a desired depth, is obtained.

The DCP readings are correlated to CBR strength values by the equation

$$\mathrm{CBR} = 2.46 - 1.12 \times \log \mathrm{DCP}$$

as determined by the Waterways Experiment Station (WES) (Webster et al. 1992). The WES database was based upon a variety of soil types.

Clegg impact tester (CIT)

The CIT (Fig. B5b) provides another means of obtaining field CBR values. It is a modified laboratory compaction hammer fitted with a piezoelectric accelerometer (Clegg 1978). The output is provided by an electronic readout. Peak decelera-

Table 4. Site characterization activities.

Activity or test device	*To determine or measure*
Clegg impact tester (CIT)	California bearing ratio (CBR) (hardness)
Dynamic cone penetrometer (DCP)	CBR
Static cone	Stiffness—cone index
Laboratory CBR test	CBR
Vitel radio frequency moisture sensors	Volumetric moisture contents
Gravimetric moisture samples	Gravimetric moisture contents
Nuclear moisture density gauge—densimeter	Density and gravimetric moisture
Thaw depth probe and soil temperature	Depth to resistance and corresponding temperature
Drive cylinders	Density/water content
Preconstruction rut depth measurements	Rut depths
Surface elevation survey	Centerline profile
Bagged samples for laboratory testing	CBR and gradation.
General site characterization evaluations	General characterization of site (e.g., % surface water, drainage, vegetation, etc.)

tion of the hammer upon impact has been shown to be a useful soil strength indicator, and regression analysis has shown good agreement with CBR (Alkire and Winters 1986). The CIT provides a low-cost method for obtaining near-surface strength data, and is generally used for low-cost, low-volume roads.

Static cone penetrometer

The static cone penetrometer is a small portable soil testing device used by military personnel to measure shear resistance as a means for evaluating trafficability (U.S. Army and Air Force 1968). It consists of a 30°, 1.3-cm (0.505-in.) diam. cone tip on a 16-mm- (0.625-in.-) diam. rod, a proving ring, a micrometer dial, and handle. The rod is held vertically, and a slow but steady downward force is applied. Proving ring deformation is proportional to the amount of force required to move the cone downward through the soil. The amount of force, considered to be an index of the soil's strength, is indicated by the dial inside the proving ring. The value determined from this reading is called the cone index (CI). Readings are typically recorded at 2.5-cm (1-in.) intervals. Additional penetration tests were conducted in remolding cylinders in the laboratory to assess the effect of repeated loads on penetration resistance. The procedure is outlined and discussed in Appendix B. Site specific results for this and other tests are shown in Appendix A.

Vitel radio frequency (RF) moisture probe

RF probes determine a soil's volumetric moisture content by measuring the soil's dielectric constant (Vitel 1994). RF probes (and time domain reflectometry [TDR] probes that operate on the same principle) are gaining rapid acceptance in the United States as a method for monitoring soil moisture content in pavement systems. The RF probe consists of a probe head, four sensing tines, and a multiconductor cable to connect to a recording device. While RF probes are generally permanently installed at several depths beneath a pavement surface to monitor moisture content as a function of time, a portable probe was used to measure near-surface moisture content for this project.

The dielectric constants of the three major constituents of moist (unfrozen) soil, e.g., soil particles, air, and water, are approximately 4, 1, and 80, respectively. It follows that the capacitance response, a function of the dielectric constant, increases appreciably as water content increases. Volumetric moisture is then determined by the Vitel probe's built-in calibration curves for specific soil types, e.g., sand, silt, and clay.

Gravimetric moisture samples

Testing for gravimetric moisture was conducted in accord with ASTM Standard D 2216 (ASTM 1985). Small soil samples were collected in moisture tins, weighed wet, oven dried, weighed dry, and the moisture contents were determined.

Drive cylinders

A drive cylinder is a hollow metal tube that is driven into the ground to extract an undisturbed soil sample. The sample weight and the known sample volume allow in-situ soil density to be determined.

Nuclear moisture density gauge/densimeter

This device, which operates by emitting low level radiation, was used to determine both moisture content and density of the surface and near-surface soil.

Thaw depth probe

A metal rod approximately 900 mm (35 in.) in length and 6.35 mm (0.25 in.) in diameter was used to determine thaw depth. The metal probe was simply pushed into the ground until it met resistance. A thermocouple at the tip of a second 762-mm- (30-in.-) long probe aided in determining whether resistance was provided by a frozen layer, i.e., approximately 0°C (32°F), or simply a hard material, such as bedrock or even a large stone (probably some temperature above approximately 0°C [32°F]).

Surface elevation surveys and preconstruction rut depths

Trail surface elevation surveys were conducted using an engineer's level and rod. The result was a centerline profile for each of the three trails. Preconstruction rut depths were also measured and recorded. "Rut depth" for this evaluation is defined as the rut's maximum depth relative to the tangent of its bounding windrows.

Site characterization forms

Site characterization forms were developed to record a variety of site characteristics that may not necessarily be reflected by discrete measurements listed above. Information recorded on site

characterization forms included estimated percent of unsurfaced trail section covered by still water, initial rut depths, etc. (App. F).

TEST SITES AND DESCRIPTION BASED UPON PRECONSTRUCTION SITE CHARACTERIZATION TESTING

Wooded trail

In its original condition, this narrow 550-m- (1800-ft-) long trail through the woods was impassable by vehicles. The travelway consisted of a thin (0 to 10-cm- [0 to 4-in.-]) vegetative/ organic mat atop a sandy soil. Gradation curves of the sandy soil are shown in Appendix A (Fig. A1a). Terrain ranged from flat to gently sloping. Although relatively flat and wet everywhere, the trail did not appear to be uniform (indicating a possible unequal frame of reference for comparing test section performance evaluation. For example, 5 cm [2 in.] of rut in a tire chip section on a dry subgrade cannot be compared to 5 cm [2 in.] of rut in a chunkwood section on a wet subgrade).

The sampling/testing grid for the wooded trail is shown in Figure A1c. Site characterization tests were conducted and samples were taken, with a few exceptions, at 7.6-m (25-ft) intervals along centerline and at 30.5-m (100-ft) intervals in the right and left wheel paths. Site characterization evaluation forms were completed for each 15.2-m (50-ft) section from station 0+00 to station 18+00 (all stations are indicated in feet). Additionally, centerline elevations were measured every 15.2 m (50 ft).

The plan and profile are shown in Figures A1d and e, respectively. Two construction crews worked simultaneously at either end of the trail, building toward the middle. The control sections near the center of the trail experienced minimal disturbance prior to trafficking, while control areas on the south end of the trail became impassable during the construction phase and required improvements. These NOGO situations are further discussed in a subsequent section dealing with vehicle mobility.

The wooded trail consisted of a saturated, thawing soil layer over frozen ground. The groundwater table was near the surface. Well-defined ruts in both wheel paths often held standing water. An estimated 25% of the entire 550-m- (1800-ft-) long trail was covered by standing water; each 15.2-m (50-ft) section ranged from 0 to 75% coverage (as shown in Fig. A1b). Gravimetric water content of nonsubmerged material ranged from 8 to 34%, and averaged approximately 19% with a standard deviation of 4.4.

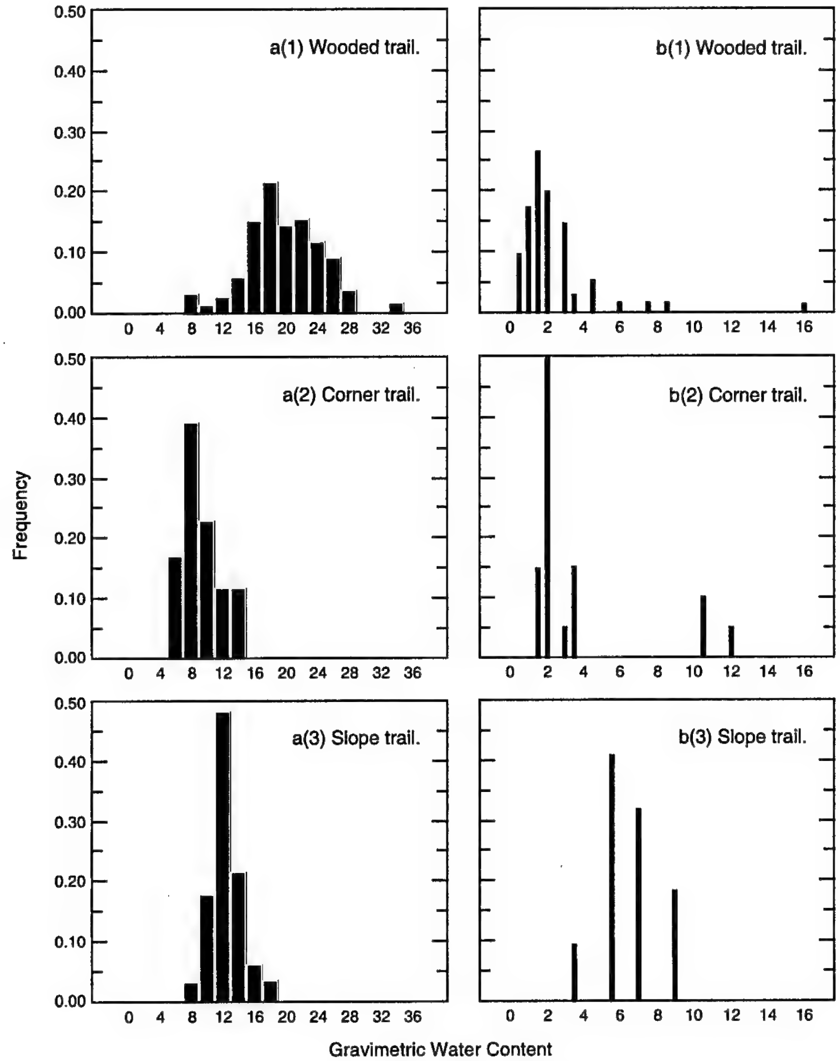
Thaw depths on the trail ranged from 10 to 41 cm (4 to 16 in.) and averaged approximately 25 cm (10 in.). Thaw depths outside the travelway (alongside the woods) were appreciably less, probably due to shading. Additionally, the right wheel path seemed to exhibit greater variability in thaw depth than did the left wheel path. Orientation and shading may have been responsible for this as well. For the wooded trail, where construction and testing spanned several days, additional soil moisture and thaw depth were measured on an interim basis to document changing conditions in the soil.

Based upon CBR_{CLEGG}, the material in the wheel paths was slightly stiffer than that along the centerline. This is probably a result of compaction due to past use/trafficking. Histograms showing the distribution of gravimetric water content and CBR are shown in Figures 1a–d. Typical CBR_{DCP} profiles for stations 6+00 and 18+00 at left, right, and center of the travelway are shown in Figure 1c. CBR in this figure was calculated using DCP values, and plotted using the Pavement-Transportation Computer Assisted Structural Engineering (PCASE) program "DCP" (U.S. Army 1995). The figure shows substantial strength variability both horizontally and vertically. Again, this provides additional evidence pointing toward a possible unequal frame of reference for test section performance evaluation.

Sloped trail

The sloped site consisted of sections of two intersecting trails. Both trail sections (collectively termed the sloped trail) had erosion gullies. Prior to site characterization and construction, the sloped trail was both graded to remove the erosion gullies and filled to yield a relatively uniform 16 to 18% grade. The corner was incorporated as a control section. Because of recent use, the sandy travel surface was not covered with an organic layer as were the wooded and pentagonal loop trails. The gradation of the sandy material is shown in Appendix A, Figure A2a. The sloped trail site is shown in Figure A2b, and the plan and profile are shown in Figures A2c and A2d, respectively.

Based upon soil sample tests, gravimetric water contents ranged from 6 to 16%, and averaged 11% with a standard deviation of 1.9. Figure A2e shows



a. Gravimetric water content histograms.

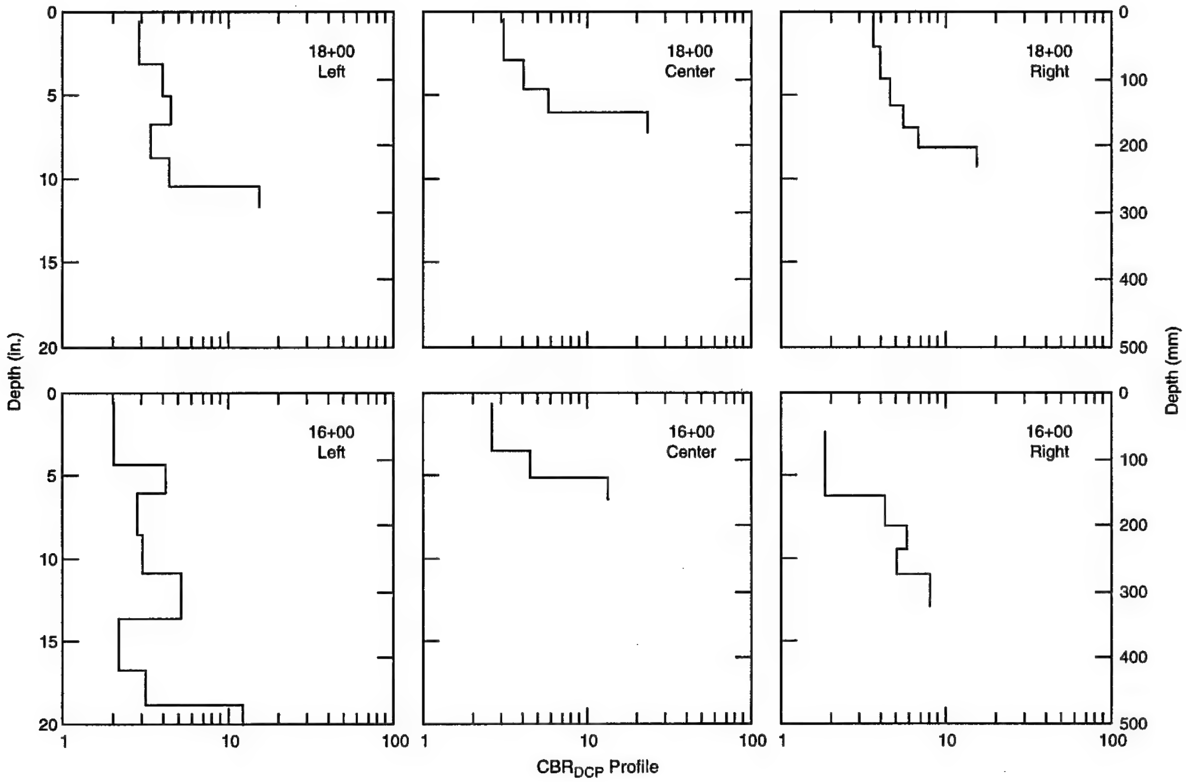
b. CBR_{CLEGG} histograms.

Figure 1. Water content and CBR.

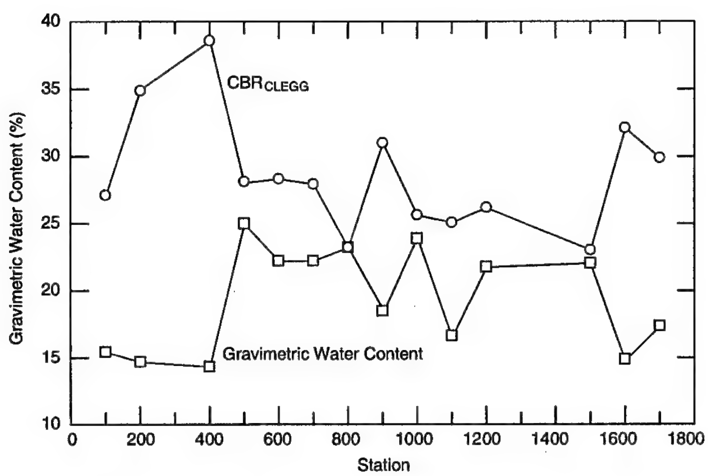
fairly uniform volumetric water contents on the north slope and highly variable water contents on the east. Resistance to penetration ranged from approximately 5 to 300 mm (0.2 to 12 in.). However, this was primarily because of bedrock as opposed to a thawed/frozen interface. CBR for the sloped trail was greater than that for the wooded trail. As would be expected, the cone index was higher in areas (near 0+00) where the depth to resistance was minimal. This, however, was not evident by CBR_{CLEGG}.

Corners: pentagonal loop trail

Performance on corners was evaluated by constructing and trafficking a pentagon-shaped loop trail (pentagonal loop trail) with approximately 33-m- (100-ft-) long sides. Test sections were centered on the corners. The trail site was flat, open, and grass covered. The native material consisted of a fine sand and was covered with a thin (0 to 8-cm [0 to 3-in.]) organic layer. The gradation of the fine sand is shown in Appendix A, Figure A3b. Prior to site characterization and test section construction, the pentagonal loop trail was backbladed with a bulldozer to flatten small berms. However, earthwork was minimal and the thin organic mat generally remained exposed during construction. In contrast to the wooded trail site, all corner test sections were constructed on visually similar terrain.



c. Typical CBR$_{DCP}$ profiles—wooded trail.



d. Gravimetric water content and CBR$_{CLEGG}$—wooded trail.

Figure 1 (cont'd). Water content and CBR.

In contrast to the wooded trail, the soil on the pentagonal loop trail was unsaturated and no frost was detected. Based upon soil sample tests, gravimetric water contents ranged from approximately 5 to 13%, and averaged 8% with a standard deviation of 2.2. The in-situ soil was the same as the unimproved sections of the wooded trail. The "soil hardness index" tests, e.g., CIT, DCP, and static cone, all indicated that the native material was also somewhat firmer than that composing the wooded trail. Despite both visual uniformity and fairly uniform cone index values (from 0–15 cm [0–6 in.], [App. A]), the pentagonal loop trail exhibited moderate strength variability. This variability was also shown by the cone index corresponding to depths greater than 15 cm (6 in.) (App. A).

Statistical correlations between site characterization parameters

Statistical analyses were conducted on site characterization and performance data to 1) explore relationships between site characteristics/soil parameters measured using various testing techniques, 2) quantify site variability, and 3) investigate the influence of site variability on test section performance. To investigate relationships between parameters measured by various testing techniques, coefficients of correlations were determined between every possible pair of parameters measured using methods outlined by Harr (1991). Quick simple tests might be used in substitution for time-consuming, complex tests (or tests requiring missing or inaccessible equipment) in instances when coefficients of correlation are high (e.g., close to +1 or –1). Conversely, if a particular test is recommended for testing a soil before proceeding with vehicle passage, information obtained by substitute test equipment that had shown low correlations. Included in this particular analysis were the following:

- Initial percent coverage of untreated travelway with standing water,
- Initial rut depths,
- Gravimetric water content,
- Volumetric water content,
- CBR determined by the Clegg impact tester,
- CBR of the uppermost 0.13-m (5-in.) layer determined by the DCP,
- Depth at which CBR reaches a value of 10,
- Static cone index corresponding to 0.15-m-(6-in.-) thick layers,
- Thaw depth,
- Density.

Correlation coefficients between centerline CBR determined by the Clegg and by the DCP were in the range of 0.7, and those between the Clegg and cone index indicated by the static cone were slightly greater than 0.6. Correlation coefficients between Clegg CBR and water content were also moderate (–0.6) and in conformance with those observed by others (Alkire 1986) and with unpublished data from other CRREL site characterization and variability testing (Kestler in prep.). A moderate correlation coefficient of approximately –0.7 was determined between gravimetric water content and CBR corresponding to the uppermost 0.13-m (5-in.) layer determined by the DCP. The figure includes only points for which a complete set of tests was conducted. Although testing apparatus differ, this is in agreement with observations by Houston (1995) who explored relations among cone resistance, water content, and soil suction in the context of subgrade variability.

Surprisingly poor correlations were observed between moisture contents determined by Vitel RF moisture probes and from small soil samples collected in moisture tins and oven dried. Although one method measures volumetric water content and the other gravimetric water content, correlations observed in other studies at CRREL to date have been good. A probable explanation is attributed to small rocks becoming lodged between Vitel probe tines. This is known to appreciably alter apparent water content, and was observed during testing at Fort McCoy's wooded trail on numerous occasions. Although expedient, the Vitel moisture probe is not recommended for soils containing small rock fragments. The above relationships can be seen in the figures provided in Appendix A. Analyses of variance (ANOVA) were also conducted using site characterization parameters. Correlations were similar to those discussed using only pairs of parameters. Regressions developed were in general only minimally improved by inclusion of multiple parameters. It is believed that tighter quality control of test methods would yield improved results for all statistical and variability analyses. Additional statistical detail on Fort McCoy site characterization is provided in Kestler (1996).

Influence of site variability on test section performance

To determine the influence of subgrade strength variability on test section performance, a geostatistical variability analysis was conducted on site characterization parameters. A geostatistical variogram shows variance of measurements made as a function of separation distance. A brief explanation of the variogram function is provided in Appendix C. For more detailed variogram development, the reader is referred to the texts by Journel and Huijbregts (1978) or Isaaks and Strivastava (1989).

Geostatistical variograms were developed for several of the preconstruction site characteristics and post-trafficking rut depths (App. C). The analysis (Kestler 1996) indicated that a rank cannot be assigned (based upon rut depths) to stabilizing techniques located at greater than two test sections apart due to variations in the subgrade.

TEST SECTION CONSTRUCTION

Mats

Four types of mats were tested: wood pallets and Uni-Mats (both wooden mats), a tire mat, and a PVC fascine mat. The Uni-Mats and tire mats were preassembled. The wood pallets and fascine mats were fabricated by the Wisconsin National Guard. They had no previous experience building or placing mats; therefore, placement methods were continually improved with each test section. Each type of mat was unique enough that a different placement method was used for each. The following sections simply discuss the placement methods used for each stabilizing technique at Fort McCoy.

Wood pallets

The mats were 1.2 × 3 m (4 × 10 ft) and constructed from rough cut 2 × 6's and 2 × 4's. A few species of wood were used. Additionally, a nail gun was used to expedite mat fabrication. Each mat was carried to and placed in the test section by a crew of seven to nine people.

On the sloped trail, the mats were placed end to end in the wheel tracks. On the wooded trail, the mats were placed three across. A line was painted on the ground as a guide to keep the mats in a straight line during placement. Mats were hand placed (Fig. 2) on both the sloped and wooded trail sections. Wood pallets were not used on the pentagonal loop trail.

Figure 2. Wood pallets.

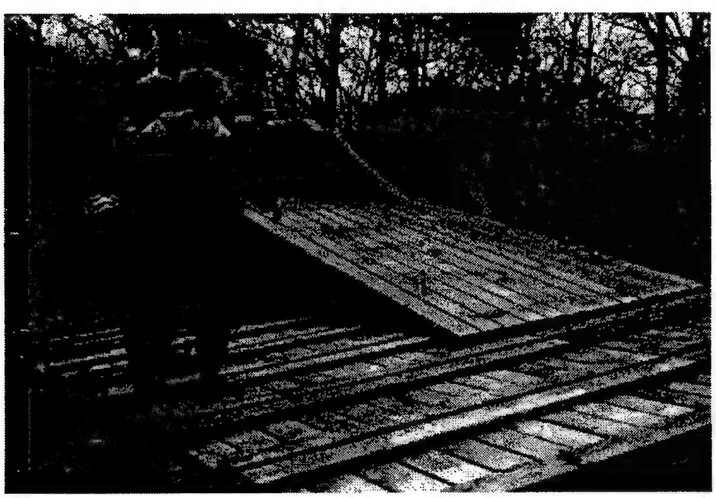


Figure 3. Lifting Uni-Mats with bucket loader.

Uni-Mats

The Uni-Mats were 2.4 m (8 ft) wide × 4.3 m (14 ft) long, weighed approximately 643 kg (1400 lb), and required heavy equipment for placement (Fig. 3). The mats are designed to interlock by placing the top layer (right side up) such that it overlaps the bottom layer (resting upside down). Uni-Mats were used on the wooded and sloped trails. In both instances, they were delivered to a staging area, then transported one at a time to the test section.

On the sloped trail, a 5CY bucket loader was used to move and place the mats. One end of the mat was placed in the bucket, while the other end was attached to the bucket with a steel cable. The mat was lifted by tipping and raising the bucket. The loader then drove to the test section and placed the mat. The bucket was lowered and tipped to place the far end of the mat. The loader then lowered the bucket and backed away. The mat was moved into position using long pry bars.

On the wooded trail, the mats were lifted using four cables and the HEMTT crane. The mat was rested on the vehicle tow assembly while being transported to the test section. One person held a tie line attached to the mat to keep the mat from swinging during backing (Fig. 4). The mat was then lowered into place. The pry bars were then used to move the mats to their final location. The HEMTT carried one mat at a time from the stag-

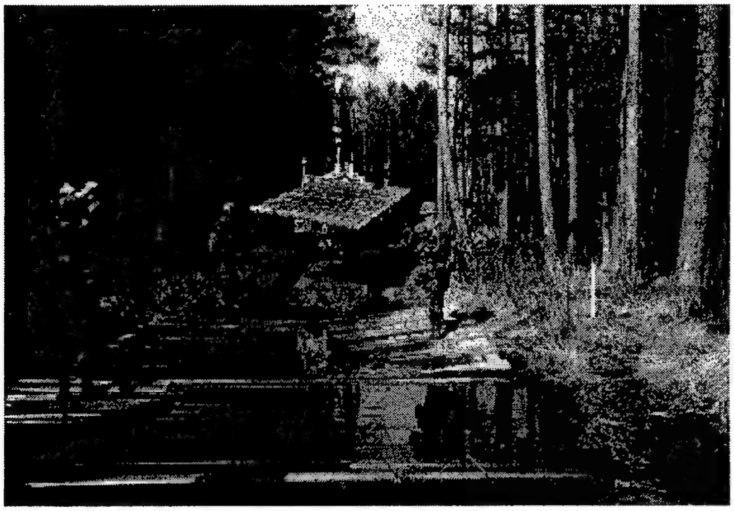


Figure 4. Placing Uni-Mats in wet site.

Figure 5. Placing tire mats onto wooded trail section.

ing area to the test section—a distance of approximately 120 m (400 ft).

Tire mats

Tire mats were provided by Terra Mat. The mats were 1.6 m (5.25 ft) wide by 3.2 m (10.5 ft) long and weighed approximately 1000 kg (2200 lb) each. There was a lifting chain at each end. The mats were placed along the wheel tracks.

On the sloped trail, the first six tire mats were moved to the test section using an all terrain forklift. The mats could not be placed using the forklift because its brakes were not adequate on the steep grade. The bucket loader was used to place these mats. One end of the tire mat was attached to the bucket and lifted from the stack. The loader then placed the lower end of the mat on the ground and lowered the mat into place. It took about one hour to place these mats. Since the all-terrain forklift could not be used to deliver the last four mats, a new method using the HEMTT was tried. The mats were arranged in two rows of two mats each. The mats in the rows were overlapped by one foot and attached together. The HEMTT then pulled the mats up the slope close to their final location. Then the HEMTT winched each set of two mats into their final position.

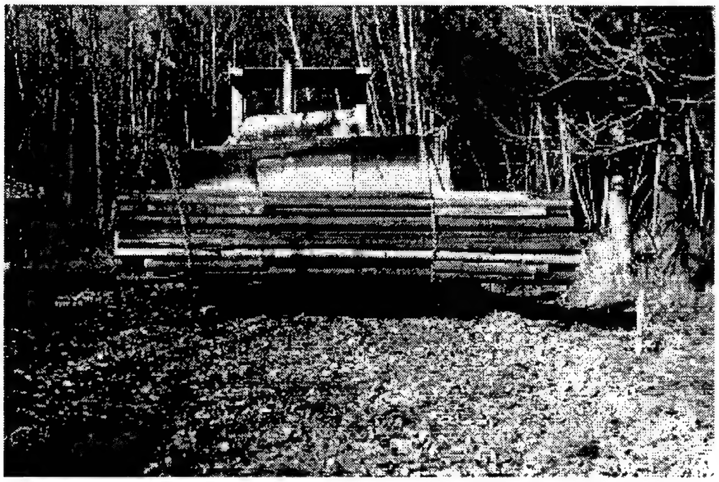
On the wooded trail, the tire mats were delivered to the north end of the wooded trail in 5-ton dump trucks. The HEMTT was then used to place the mats. First, the mats were laid end-to-end with 0.3 m (1 ft) of the second mat lying on top of the first, etc., until eight mats were laid out. The mats were then fastened together. Plans were to drag the mats in a manner similar to that used on the sloped trail. This method failed because the chain on one of the mats broke. The mats were then arranged in a stack of four and carried/dragged by the HEMTT (Fig. 5) to the test section where they were placed close to their desired position. Each mat was then picked up individually and placed in position.

On the pentagonal loop trail, the tire mats were delivered on a lowboy, off-loaded, and placed with a bucket loader with teeth. The test section shape was then modified to "round" the corners. A D7 bulldozer was used to move the mats into their new position.

PVC fascine mats

A fascine is a series of parallel pipes placed to fill a ditch that allows traffic to travel across (Fig. 6a). In contrast to a typical military fascine, the fascine mats used for this demonstration project were constructed of materials similar to those used by the USFS (Mason 1990), e.g., 6-m- (20-ft-) long schedule 80 PVC pipe, 1.6 cm (5/8 in.) steel cable and cable clamps. Two 4.6-m- (15-ft-) long by 4.9-m- (16-ft-) wide fascines were constructed.

The fascine was used in two locations on the wooded trail. The first location was at a bend in the trail where the tank had thrown a track just



a. Fascine.

b. Covered with chunkwood.

Figure 6. PVC fascine.

Figure 7. Spreading fill material with D7 bulldozer.

prior to the demonstration. Water, approximately 10–20 cm (4–8 in.) deep, was flowing across the trail. By use of a D7 bulldozer, the fascine was moved into place, placed on top of a geotextile, and covered with chunkwood.

The second location was another area where water was flowing across the trail. The HEMTT was used to transport the fascine to this test section. The fascine was unrolled so it was only one pipe thick (Fig. 6), and covered with tire mats.

Overall comments on all mats

Test site construction could have been more efficient if the delivery truck had unloaded the mats at the test site. This would have enabled the construction crew to work continuously. As an alternative, the mats could have been brought to the staging area on a lowboy and then transferred to the construction site using a cargo HEMTT with a crane.

Fill materials

Three types of fill material were used: chunkwood mixed with sand, tire chips, and gravel. Similar construction methods were used to place all three. The material was loaded into dump trucks, delivered to the site, and then spread with a D7 bulldozer (Fig. 7). Hauling distance figured significantly in overall construction time.

Chunkwood

The chunkwood was produced by shredding whole trees with a USFS prototype wood chunking machine. The resulting wood chunks were approximately 3.8 cm (1.5 in.) thick and were well graded, ranging from 1 to 20 cm (0.5 to 8 in.) in diameter. The chunkwood was mixed with sand in the approximate ratio of three parts chunkwood to one part sand. The density of the chunkwood/sand mix was approximately 796 kg/m^3 (50 lb/ft^3). The bulking factor appeared to be low. Although testing by the USFS has shown a sheepsfoot or padfoot roller improves compaction, the chunkwood compacted easily with construction vehicle traffic. The compacted surface was relatively smooth and provided a good wear surface (Fig. 8).

a. Chunkwood fill.

b. USDA Forest Service wood chunker.

Figure 8. Chunkwood.

Tire chips

The tire chips were produced by shredding car and truck tires until they passed a 5-cm (2-in.) screen. There was a significant amount of bead steel mixed with the tire chips. The tire chips had a density of approximately 643 kg/m^3 (40 lb/ft^3). The bulking factor appeared to be low. The tire chips did not appear to compact significantly; the surface remained springy even after several passes of a D7 bulldozer.

Gravel

The gravel was obtained from a stockpile at Fort McCoy. It is used for their conventional gravel roads. The gravel had a density of approximately 1922 kg/m^3 (120 lb/ft^3). The gravel compacted easily by construction trafficking and provided a good wear surface.

Slash

The slash was produced by first felling trees, loading them in trucks, and delivering them to the test sections. Trees with diameters less than 20 cm (8 in.) were used on the slope. The maximum diameter used for other test sections was approximately 8 cm (3 in.). A variety of species were used.

Slash was transported to the sloped trail test section in 5-ton dump trucks as whole trees. The trees were then cut up by chainsaws so they could be moved by hand and placed on the trail generally perpendicular to the direction of travel. The

Figure 9a. Slash—pentagonal loop trail.

b. Larger diameter logs used to fill large rut.

Figure 9. Slash.

recommended maximum size log was 20-cm (8-in.) diameter.

The slash test section on the wooded trail was 30 m (100 ft) long; the southern 15 m (50 ft) was covered with a geotextile before construction began. There was a large rut in the easterly wheel path in the slash test section. This rut was filled with logs (approx. 15 cm [6 in.] in diam.), running parallel to the rut (Fig. 9b). It took about five rows of logs to fill the rut. Next the slash was delivered. In this test section, the maximum diameter slash allowed was 8 cm (3 in.). The first few truckloads had trees that were larger than 8 cm (3 in.) in diameter. These trees were delivered to the site, cut up on site, and placed. The remaining trucks had slash that was already less than 8 cm (3 in.) in diameter.

On the pentagonal loop trail, the slash was laid in two layers in a herringbone pattern. The first layer was placed at a 45° angle to the direction of travel. The second layer was 90° to the first layer. Only slash under 8-cm (3-in.) diameter was used.

Geotextiles

Geotextiles, used at each of the test sites, were placed quickly and required minimal personnel. Sections of material were unrolled, cut and placed by hand. They were dragged into place on the slope and forklifted onto the wooded trails.

To prevent slipping and bunching of fabric during trafficking, anchoring techniques were tried in the field, but these techniques require further development. Cover was used wherever tank turning/cornering was anticipated.

TEST SECTION PERFORMANCE EVALUATION

The HEMTT used for trafficking was a M984E1 wrecker/recovery vehicle in good condition. It was operated using both on- and off-road recommended tire pressures. On-road tire inflation pressures for the HEMTT are 413 kPa (60 psi) on the four front tires and 689 kPa (100 psi) on the four rear tires. The recommended pressures for off-road are 138 kPa (20 psi) on the four front tires and 689 kPa (100 psi) on the four rear tires. Although the ride and traction were vastly improved using the off-road pressure, steering was less responsive.

The M60A3 tank was in marginal condition and worn sprockets likely contributed to the loss of a track during the initial passes on the wooded trail prior to construction.

After test sections were built, the trail was trafficked 50 passes with an M60A3 (M60) tank and 50 passes with an M984E1 wrecker/recovery HEMTT (App. G). Sloped trail test sections also included a test of the surface traction by climbing from a stop and downhill braking on each test surface. The pentagonal loop trail was trafficked

with the M60 and not the HEMTT, because tracks are significantly more destructive on corners. The drivers attempted a constant vehicle speed over all the sections 16 to 32 km/h (10 to 20 mph) and any significant speed variation caused by the surfaces was recorded.

The performance of vehicles and test sections was evaluated after 1, 10, 25, and 50 passes of each vehicle. Each test section was evaluated for rutting, lateral expansion of the trail, failure of the surface material, interference of the material with the vehicle, movement of the surface material, vehicle slipping, repairs, etc. The vehicle drivers evaluated the performance of the test sections with respect to vehicle operation, loss in traction, braking, vehicle handling and steering, necessary adjustments to vehicle speed, material interference with vehicle components, etc. The drivers also gave each test surface an overall ranking, as indicated on the sample evaluation forms, also provided in Appendix G. Final observations and photo documentation of each test section were completed after each vehicle completed the 50 passes. The vehicle drivers and test section evaluators were then interviewed on video to document users' thoughts and ideas, expanding on the written surveys.

As mentioned earlier, all of the stabilization techniques tested in this program improve soil bearing capacity by distributing traffic loads over a larger area. "Rigid" materials with flexural stiffness (i.e., wooden mats, slash and possibly to a small degree, the geonet) distribute loads to the thawing soil largely through beam action. Chunkwood and tire chips are alternatives to the use of granular fill placed on lower bearing capacity subgrades to help bear traffic loads. For subgrade CBRs of 1 to 3, a geotextile is needed to keep fill and subgrade soil separate. At CBR values less than 1.0, geotextiles or geogrids often provide reinforcement as well as separation. When used with little or perhaps even no fill, high strength/high modulus geosynthetics can help bear loads through "membrane support" of the wheel loads (Fig. 10) (Giroud and Noiray 1981). Membrane support refers to the deformation and tensioning of the geosynthetic to help bear the traffic load (i.e., ruts must form in the geosynthetic). Even though the stabilization techniques tested were not specifically chosen for their ability to improve traction, qualitative observations of traction were documented.

The remainder of this section describes the trafficking tests that were conducted and observations made during and after the tests.

Sloped trail

Trafficking of the sloped test site occurred over three days. It began on 20 March 1995, with the HEMTT making 30 passes. The weather was snowy, rainy, and windy. On 21 March 1995, the weather cleared and the HEMTT made an additional 20 passes followed by 25 passes with the M60 tank. Tank trafficking finished with 25 passes on 22 March 1995. The weather was sunny and clear and the soil appeared to be drier on the third day of trafficking.

After the HEMTT and before tank trafficking began, one 20-cm- (8-in.-) diam. tree trunk was removed from the slash test section at the request

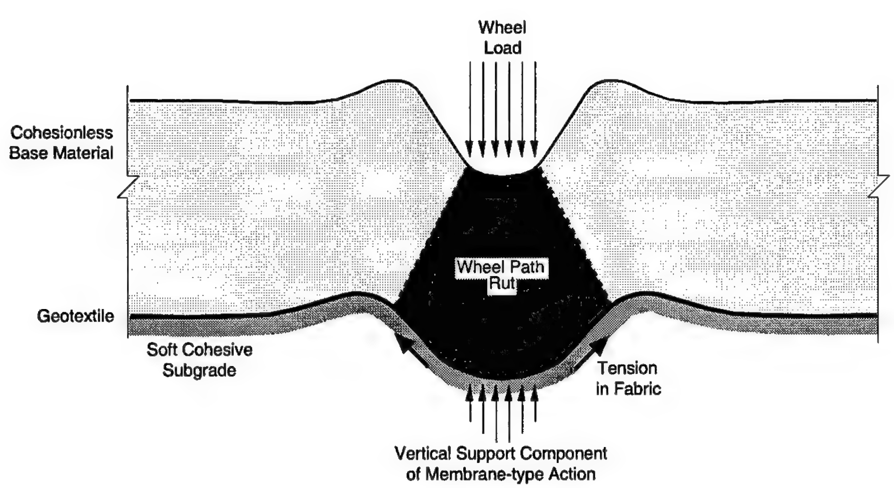


Figure 10. Membrane support (Giroud and Noiray 1981).

of the tank driver. Another tree of about the same size was removed on the morning of 22 March, also at the request of the driver.

On the morning of 22 March, a bulldozer trafficked the test sections to make repairs to the turnaround locations at the end of the test area, to the control sections, and to the chunkwood and tire chips (bladed out the ruts), all of which were deeply rutted. There was no apparent damage from the bulldozer to any of the test sections except for a 75-cm- (2.5-ft-) long tear in the double-sided geonet. Ruts formed over the Geonet and Polyrock (after 25 passes) were filled in with in-situ soil and some larger objects (e.g., rocks and logs). This provided minimal anchoring because there wasn't enough material mass to weight it down, since the ruts were about 15 cm (6 in.) deep at the maximum.

Wooded trail

The wooded trail was first trafficked with 50 passes of the M60 tank on 24 March 1995. Just prior to trafficking, a 22,500-L (6000-gal.) water truck made two passes applying water at an even rate along the test section for the purpose of ensuring high moisture content conditions. On 25 March 1995, several repairs were made to the wooded trail, and trafficking continued with the HEMTT on 26 March 1995.

Pentagonal loop trail

The M60 trafficked the pentagonal loop trail in order to observe the behavior of various stabilization materials when a tank cornered on them. Fifty passes with the M60 tank were made on 25 March 1995. The weather was cloudy and cool. The soil was notably dry, especially compared to the other test sections. The pentagonal loop trail was not trafficked with the HEMTT.

Test section performance—durability

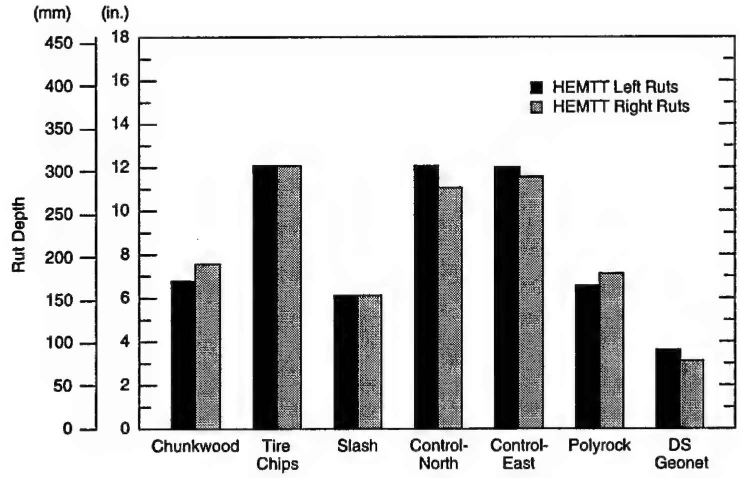
Table E1 summarizes observations and test section performance and briefly discusses how each technique could be improved for future testing and use. Detailed observations of each test section are contained in Appendix E. Left and right rut depths for each trail after HEMTT trafficking are shown in Figure 11. As discussed in the site characterization section, in most instances, stabilizing techniques cannot be ranked by directly comparing rut depths, as stabilization techniques separated by any appreciable distance were constructed on virtually different subgrades. Just one of the many factors influencing rut depth is shown in Table A1f—thaw depths on the wooded trail at the end of trafficking (App. A).

Test section performance—vehicle mobility

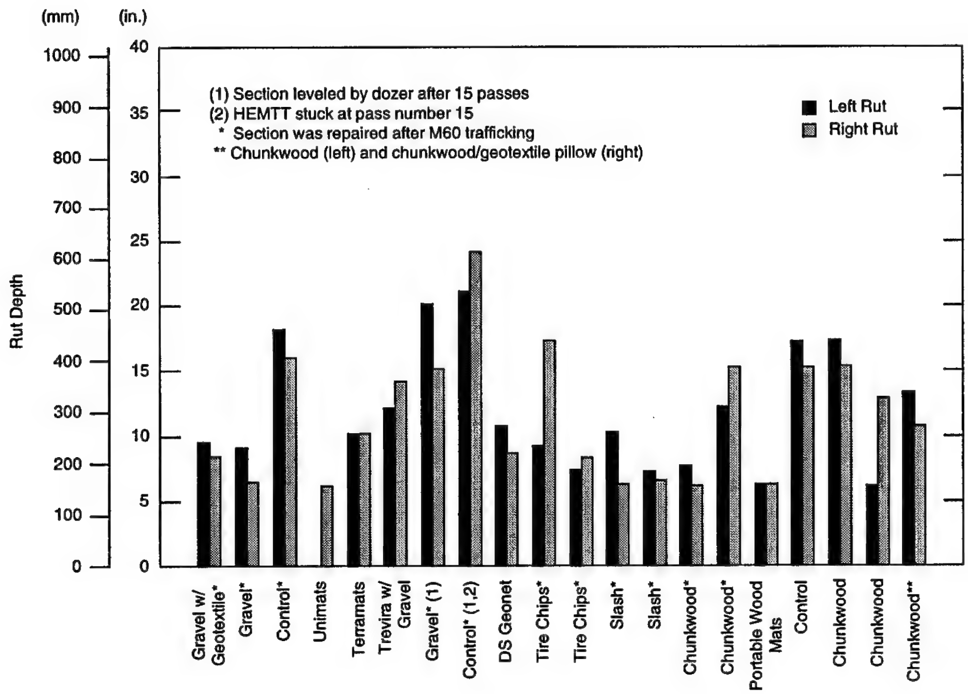
The performance of each vehicle on each of the test surfaces and control was documented using the driver survey form querying the condition of the vehicle, experience of the driver, how and when there was any interference of the test surface with the vehicle, and how the test surface affected the vehicle performance in terms of traction, slipping, speed, handling, etc. An example form is given in Appendix G. The driver's rating of the test surfaces along with driver comments is summarized in Table 5. Additional comments from the drivers were that some materials (such as the chunkwood and slash on the wooded trail) were placed in locations with few adverse factors affecting their survivability (such as no steering required, no standing water prior to construction), while others were placed in positions where they were doomed to failure (such as poor width spacing of the tire mats on very soft soil and standing water on the wooded trail). Indeed, site variability analysis already discussed indicates nonuniform conditions.

A NOGO condition (see App. H) is defined as a terrain or surface condition that results in a vehicle becoming immobile. Additionally, conditions where the driver chooses not to proceed further upon serious damage to the vehicle or surface, resulting in immobilization, are also considered NOGO situations. NOGO conditions occurred during the construction and testing of the test surfaces as follows:

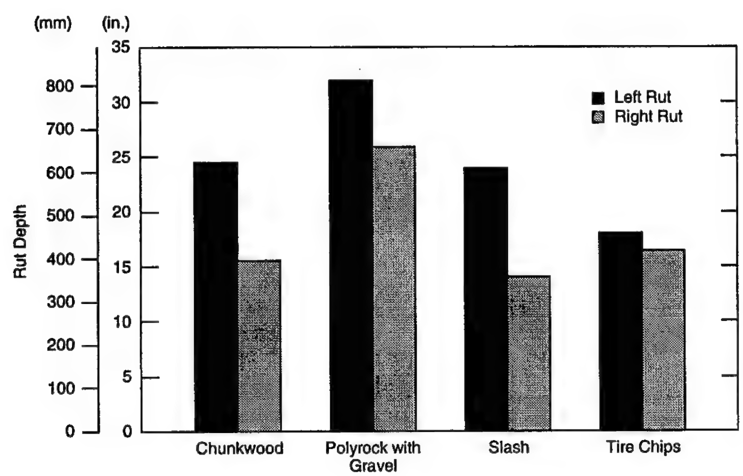
- The M60A3 threw a track while rounding a corner on the wooded trail prior to construction of test sections.
- Tire chip pretest caused flat tires on the CJ5 after only three passes (note: tires were previously in poor condition).
- Larger pieces of slash on the slopes had to be removed to prevent interference and possible throwing of the tank track (Fig. 12).
- Unanchored, bare polypropylene TS1000 geotextile on the wooded trail (16+50 to 17+75) did not provide adequate flotation for the construction vehicles and was covered with chunkwood after approximately 20 passes with 5-ton dump truck.
- The 14+75 to 15+50 control section on the wooded trail become impassable during con-



a. Sloped trail.



b. Wooded trail.



c. Pentagonal loop trail.

Figure 11. Rut depths.

Table 5. Driver's rating of test surface.

	HEMTT trail	*M60A3 trail*	*HEMTT slopes*	*M60A3 slopes*	*M60A3 corners*	*Slip during hard braking*	*Comments*
Vehicle speed km/hr (mph)	16–24 (10–15)	19–24 (12–15)	8–16 (5–10)	8–16 (5–10)	8–11 (5–7)		
Chunkwood over TS1000	1	1					
Chunkwood w/sand	1	3			3		Problems with steering, track walking off sprockets after 10 passes (M60 on corners)
Chunkwood (old control)	1	1					
Pallets	1	1	2	2		some	Traction loss and much breakage after 10 passes on (M60 slopes)
Chunkwood corner	1	1					
Chunkwood	1	1	1	1		none	
Slash	2	1	5	4	2		Material gets caught in tracks after 10 passes and must be pulled out by hand (M60 on corners) (Fig. 12) Material interference (worried about brake lines), slipping, rough ride and poor vehicle handling after a single pass (HEMTT on slopes) Material interferes with tracks after 10 passes and causes steering and handling problems after 50 passes (M60 on slopes)
Tire chips	2.5	1	1	1	3	some	Good traction but steering problems after 25 passes Enhanced by tire pressures (HEMTT on trail) Good traction, smooth ride (HEMTT on slopes) Steering problems after 10 passes, track walking off sprockets (M60 on corners)
Geonet	1	1	1.5	3		some	Traction loss after 10 passes, bunched during braking (M60 on slopes) Good traction but fabric moves along slope (HEMTT on slopes)
Control	5	4					Slipping and steering problems after 10 passes (HEMTT on wooded trail)
Gravel		3					Gravel displaced by tracks, no cohesion (M60 on trail)
Polyrock		2	1.5	1		some	Good traction but fabric moves along slope (HEMTT on slopes)
Trevira w/gravel cover	1						
Tire mats	2	3	1	1	4	HEMTT some M60 none	Mats moved together after 25 passes because they were not centered under tracks (M60A3 wooded trail) Material interfering with track after 10 passes, removed because of severe interference after 25 passes, gradual corners will increase survivability, anchoring mats may help (M60 on corners) Rough ride, some handling problems after 10 passes (HEMTT on slopes)
Fascine	1	2					
Uni–Mats	1	2	5	3		HEMTT some M60 lots	Traction and handling problems after a single pass (HEMTT on slopes) Traction loss and vehicle handling and steering problems after 10 passes (M60 on slopes)
Control	1	1					
Gravel	1	1					

Rating: 1 = excellent, no problems
2 = slowed down some, rough ride
3 = some slipping, steering problems
4 = difficult to traverse
5 = very difficult to traverse, got stuck

Figure 12. Tree slash caught in tracks during cornering.

Figure 13. HEMTT stuck in wooded trail control section, station 7+00 – 8+00.

struction (after approximately 20 passes of fully loaded 5-ton trucks).

- Control section 7+00 to 8+20 on the wooded trail became impassable after only 15 passes of the HEMTT (it was not a problem with the tank) due to rut depths exceeding vehicle ground clearance (Fig. 13).
- Control section 2+50 to 3+50 threatened NOGO on the north end of the wooded trail when it filled with chunkwood after pass 25 of the HEMTT due to severe rutting.
- The tire mat section on the corners became impassable after 25 passes of the M60 because of the mats catching in the tank track and being thrown out of position. The mats were moved aside for the remainder of the passes.

Appendix H summarizes the soil conditions for the NOGO situations encountered on the wooded trail.

DECISION AID AND GUIDELINES FOR SELECTING STABILIZATION TECHNIQUES

All techniques used at Fort McCoy improve the condition of the trail. The best technique depends on a variety of criteria. Table 6 can be used as an engineering decision aid for selecting surfacing techniques. These criteria (e.g., training, cornering, etc.) can be used as guidelines for rating stabilizing surfaces listed and can be readily

Table 6. Decision aid and guidelines for selecting rapid stabilization techniques for vehicle mobility on thawing ground.

	Gravel road	*Tree slash*	*Uni-Mats*	*Small pallets*	*Chunk wood*	*Tire mats*	*Tire chips*	*Geonet*	*High strength geotextile*[l]	*PVC fascine*
Overall trafficability, driver surveys 1=excellent, 5=poor	2	2–3	2–3	1–2	1–2	1–3	1–2	1–2	3–4[i]	N/A
Cornering survive ability 1=excellent, 5=poor	3	4	3	4–5	4	4–5	4	5[j]	5[j]	4[h]
Traction (slopes) 1=excellent, 5=poor	2	3–4	4–5	2–4	1	1	2	3	3	N/A
Material/vehicle interference 1=none, 5=high potential	1	5	1	1	2	2	2[k]	5[j]	5[j]	2[h]
Foot traffic 1 =easy, 5=diffficult	1	5	2	2	2	4	3[g]	1	1	N/A
Material life expectancy P=permanent (>5 yr), T=temporary	P	T	T/P	T	T/P	T/P	P	T	T	T/P
Localized section (LS) for repair or entire road ?	either	LS	LS	LS	either	LS	either	either	either	LS
Material availability[a] 1=local store 5=must be ordered	1	1[b]	4–5	1–2	5[d]	4–5	4–5	3–5	3–5	2-4
Equipment required 1=standard equipments 5=special equipment	1	1	3	1	5[d]	3	1	1	1	1
Training 1=minimal, 5=special	1–2	1	2	1	3[d]	2	2	1	1	2
Material preparation 1=Easy, 5=Labor intensive	2–5[e]	5	1	4	5	1	1	1	1	4
Material placement 1=easy, 5=labor intensive	2–3	5	2–4	3	2	2–3	2–3	2–4[f]	2–4[f]	2
Material cost 1=low, 5=high	1	1	5	2	2	2	5	3	3	2
Potential exposure to enemy fire (during placement) 1=low, 5=high	1	5	4	3	1	3	1	3	3	3

[a] Availability of proximity to forests, lumberyards, etc.
[b] If no trees, old corn husks, etc.
[c] Std equipment: dozer, loader, and dump truck.
[d] USDA Forest Service has 2 prototype woodchunkers.
[e] Including borrow pit development.
[f] Including anchoring.
[g] Pieces of metal may penetrate shoes or tires.
[h] Typically PVC fascine is surfaced with grating or wood mat.
[i] Needs cover material.
[j] If unsurfaced, geotextile can become entangled in tank tracks.
[k] Omit steel bead to run rubber tired vehicles
[l] Geosynthetics used with no surface cover.

extended to those not listed. Effectiveness of any technique is a function of many variables. What is the life expectancy of the road? (Is the purpose of the road rapid deployment indicating a temporary road, or will it serve as the base of a future road as in rebuilding an infrastructure in a war-torn environment?) How about exposure to enemy fire? Tree slash may be readily available, but placement is extremely labor intensive and requires extensive periods of exposure by personnel. Equipment availability may eliminate a particular technique or process. The site may be in a forested area, but without a wood chunker or wood chipper, chunkwood or wood chips are clearly eliminated. Likewise, if foot traffic or passage with small rubber tired vehicles is anticipated, tire chips including steel bead should not be used as a wear surface. The steel pieces in tire chips have been shown to puncture both rubber tires and boots.

We are not restricting recommendations to only those techniques listed. Only mechanical stabilizing techniques were demonstrated. Neither chemical nor chemical-mechanical techniques were considered. Additionally, only a limited number of surfaces representative of each stabilization principle were discussed. For example, portable wood pallets and prefabricated large wood mats were considered representative of rigid mats. However, there also exist a variety of rigid mats made of fiberglass and "high-tech" plastics. Many of these mats are lightweight and high strength. While material costs are generally higher than wood products, the ground area covered by one truckload/planeload of fiberglass mats is appreciably larger than the area covered by heavier, more bulky wood mats. Tradeoffs must be considered in selection. If it is known that delivery will be limited, the more expensive, lighter weight mats would be recommended.

SUMMARY AND CONCLUSIONS

The following discussion briefly summarizes Tables E1 and 6, taking into account construction, test section performance, and vehicle/mobility aspects of the demonstration project.

Conventional road

A conventional gravel road is unquestionably one of the simplest of the techniques demonstrated. Dump trucks, loaders, and bulldozers are standard equipment. The problem, of course, is availability of material. It is possible that aggregate sources are simply unavailable. Because thawing is the source of the immobility problems addressed here, borrow sources may still be frozen, inaccessible, or of poor quality, and susceptible to thaw weakening.

Chunkwood

Chunkwood proved to be an excellent substitute for gravel for the Fort McCoy demonstration project. Not only was it successfully used in test sections as planned, but it also served as the mainstay stabilization technique for the entire project. When access roads to test sites became impassable, chunkwood was used to reconstruct and allow passage. Because of its low density, it can be supported by very weak subgrades that might not be capable of supporting necessary aggregate. A gravel wear surface can be added for use as a permanent road. As a base course beneath gravel cover, the chunkwood provides an excellent insulating layer to reduce detrimental effects of frost action in areas of seasonal freezing. However, chunkwood's success relies on the availability of a source of trees and the development of a commercial chunker. It is possible that more conventional wood chips may serve in a similar capacity to chunkwood; additional testing is recommended.

Tire chips

As was the case of conventional roads and chunkwood, construction requires no special equipment or training. Tire chips can be supported by weak subgrades not capable of supporting a gravel embankment. As with chunkwood, a gravel wear surface can be added, and the tire chips provide an excellent insulating layer. Another advantage of tire chips is utilization of a waste product. However, it is imperative that no steel bead or foreign steel pieces be contained in the tire chips, if the road is to be used as a trafficking surface for small rubber-tired vehicles (or foot travel). Additionally, environmental concerns (some states prohibit tire chip base courses when placed below the seasonal high water table) and flammability need to be addressed.

Tree slash

Tree slash is inexpensive and placement requires no special equipment or training. Its availability is slightly broader than that of chunkwood simply because scrub brush, old corn husks, or any bulk vegetative material may be used. A major drawback is that placement is labor intensive

and could potentially expose construction personnel to enemy fire. Like tire chips, it is not a desirable surface for small rubber-tired vehicle passage or foot traffic; walking is *extremely* difficult. Tree slash can also puncture and damage hydraulic hoses on the underside of equipment.

Prefabricated large wood mats (Uni-Mats)

Although tank cornering was not tested on Uni-Mats during this demonstration project, its success in cornering on relatively level terrain has been documented elsewhere. Uni-Mats seem to be the only surface that can withstand the trauma of tank tracks undergoing cornering. They are not designed for bridging large ruts and were slippery on slopes particularly when wet. Uni-Mats are extremely heavy and require specialized equipment for placement.

Small portable wood pallets

Constructing these on site requires time and labor. However, ease of placement for the effectiveness of performance is a plus. Lumber is typically available almost anywhere and is inexpensive. Mats were broken during tank trafficking, but they continued to performed well (stabilized a weak thawing soil to adequately support trafficking). A strong species of wood is necessary if re-use is expected; however, this can double the cost of the pallets.

Tire mats

Tire mats performed very well except for tank cornering. Placement requires heavy equipment. For expediency, a lighter mat would be easier to handle.

PVC fascine

No special equipment was required, and the fascine mats could be constructed on site. For this demonstration, we decided to save on materials by having a full mat (contiguous pipes) for the tire tracks (wheel paths) with gaps between wheel paths. The pipes partially silted in impeding water flow through them. However, they provided a stabilized surface.

Geosynthetics

All geosynthetics were placed quickly and with minimal labor. They are lightweight and easy to handle compared to the other surfaces. If unsurfaced, geosynthetics can become entangled in tank tracks. Cover improves performance and was necessary for most cases. Anchoring techniques require further development.

Techniques used in combination

Each of the above techniques serves some portion of the design function, and combinations of methods often proved to be more effective than any individual method.

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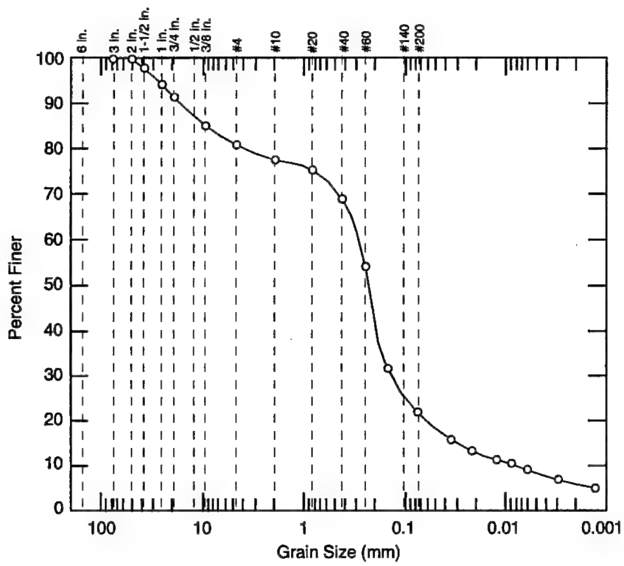
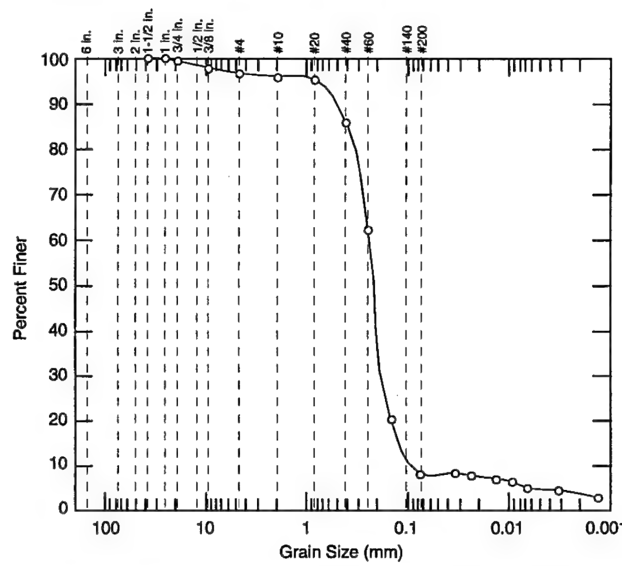
APPENDIX A: SITE CHARACTERIZATION DATA



	% +3"	% Gravel	% Sand	% Silt	% Clay
o	0.0	19.4	59.2	13.6	7.8

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o	none	none	9.33	0.292	0.228	0.144	0.0308	0.0090	7.91	32.1

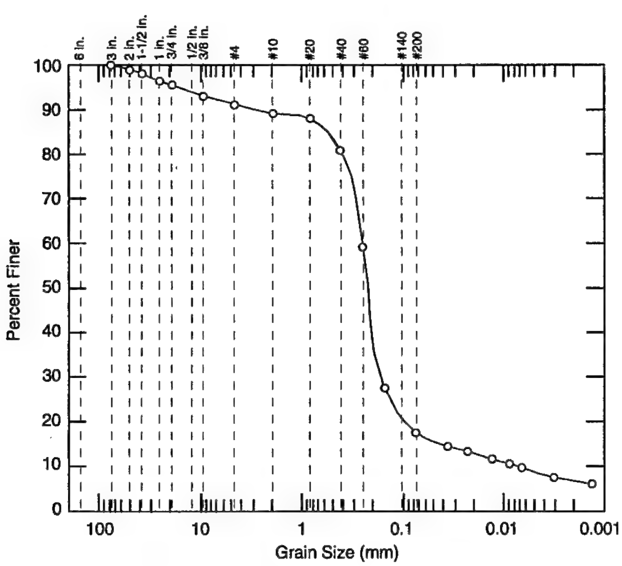
Material Description	USCS	AASHTO
o Wooded Trail Station 8+25	SM	A-2-4



	% +3"	% Gravel	% Sand	% Silt	% Clay
o	0.0	3.5	87.8	4.3	4.4

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			0.407	0.243	0.216	0.172	0.135	0.113	1.07	2.1

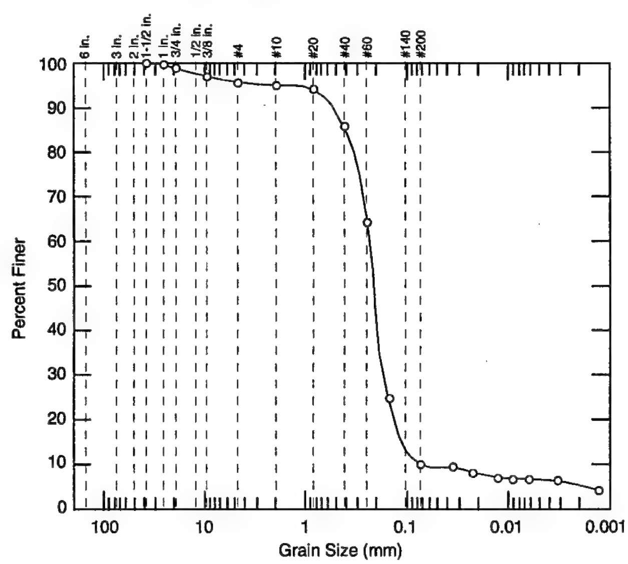
Material Description	USCS	AASHTO
o Poorly Graded Sand with Silt o Wooded Trail Chunkwood Station	SP-SM	A-3



	% +3"	% Gravel	% Sand	% Silt	% Clay
o	0.0	9.0	73.9	8.9	8.2

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			0.531	0.254	0.218	0.159	0.0443	0.0086	11.52	29.4

Material Description	USCS	AASHTO
o Wooded Trail Station 16+50	SM	A-2-4



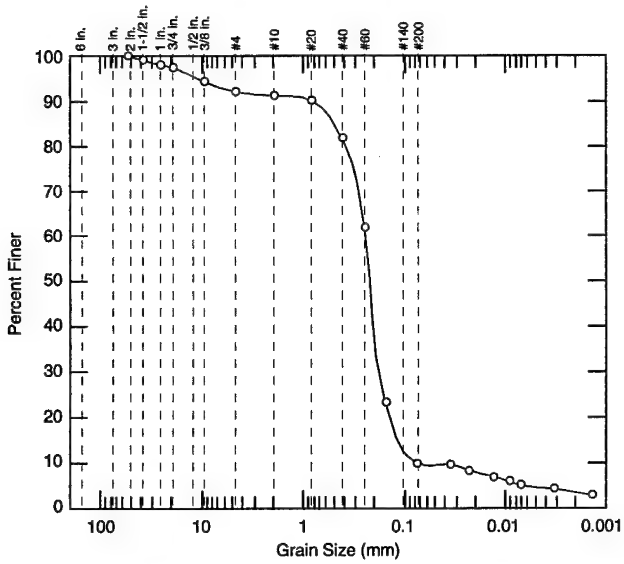
	% +3"	% Gravel	% Sand	% Silt	% Clay
o	0.0	4.6	86.0	3.2	6.2

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			0.407	0.237	0.209	0.163	0.121	0.0896	1.25	2.6

Material Description	USCS	AASHTO
o Wooded Trail Station 1+50	SP-SM	A-3

a. Gradation curves—wooded trail.

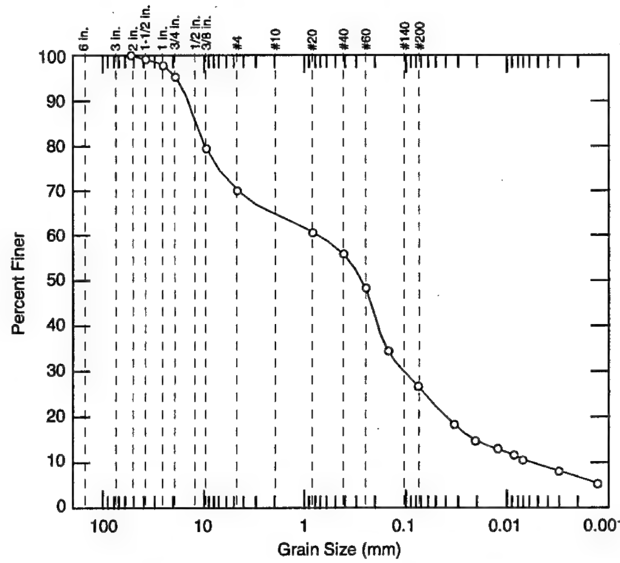
Figure A1. Wooded trail.



	% +3"	% Gravel	% Sand	% Silt	% Clay
o	0.0	8.1	82.2	5.2	4.5

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			0.501	0.242	0.213	0.166	0.125	0.0930	1.22	2.6

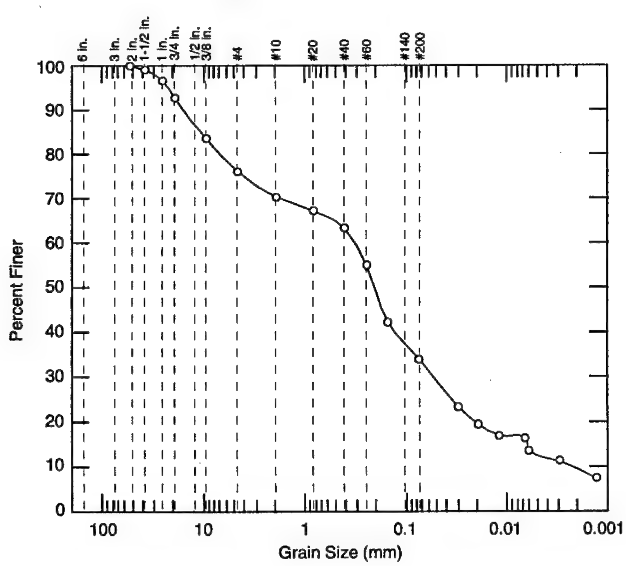
Material Description	USCS	AASHTO
o Poorly Graded Sand with Silt o Wooded Trail Control Station 5+00	SP-SM	A-3



	% +3"	% Gravel	% Sand	% Silt	% Clay
o	0.0	30.0	43.4	17.6	9.0

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			12.0	0.749	0.269	0.115	0.0226	0.0067	2.63	112.2

Material Description	USCS	AASHTO
o Silty Sand with Gravel o Wooded Trail Station 5+00, West Side Road	SM	A-2-4



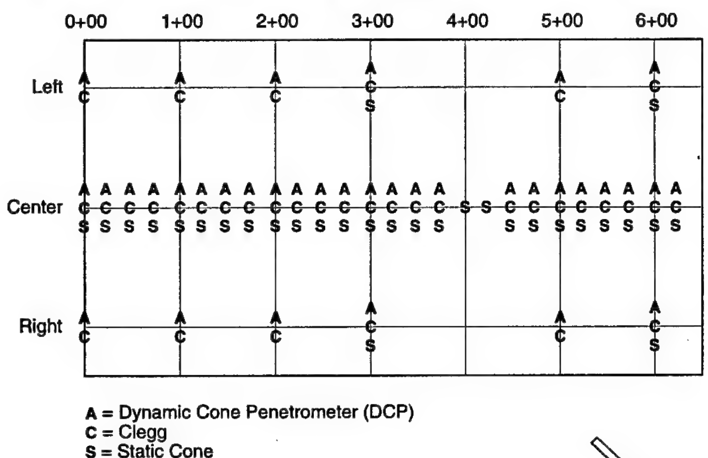
	% +3"	% Gravel	% Sand	% Silt	% Clay
o	0.0	23.9	42.3	21.8	12.0

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			11.1	0.316	0.203	0.0528	0.0063	0.0025	3.54	126.6

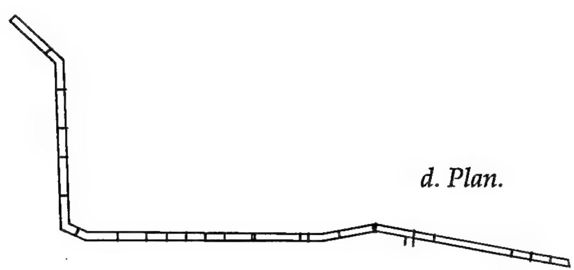
Material Description	USCS	AASHTO
o Silty Sand with Gravel o Wooded Trail Station 7+25, West Side Road	SM	A-2-4

a (cont'd).

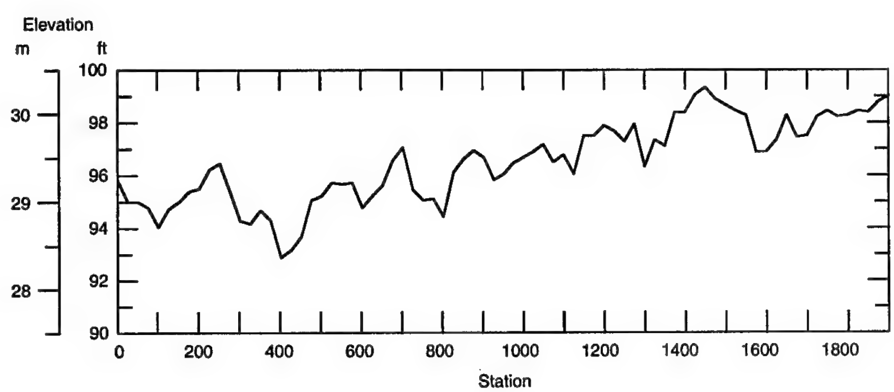
b. Wooded trail site prior to construction.



c. Typical sampling and testing grid.

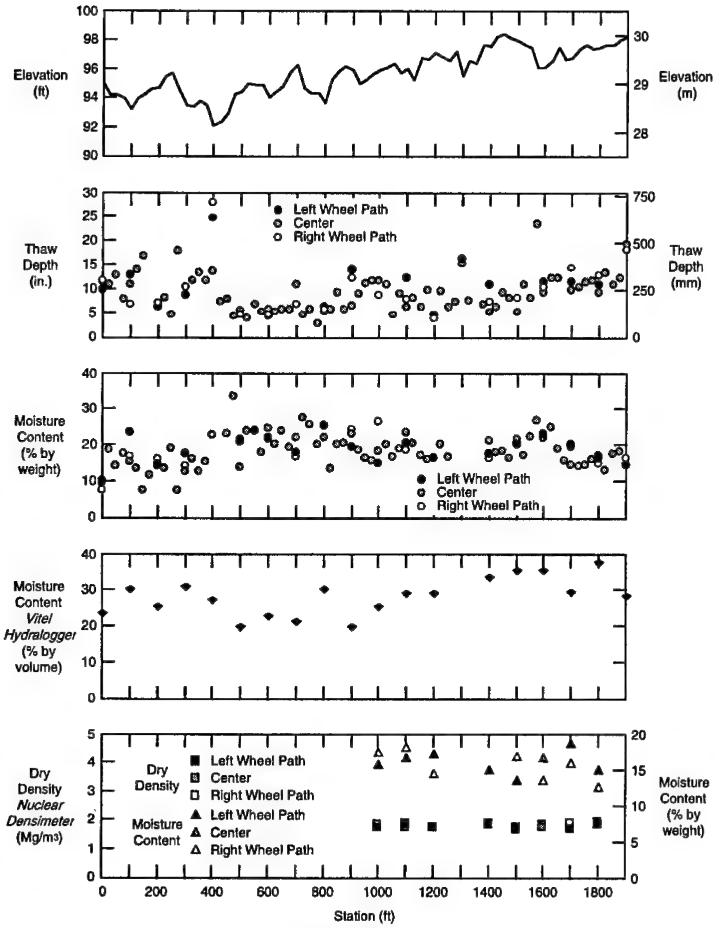


d. Plan.

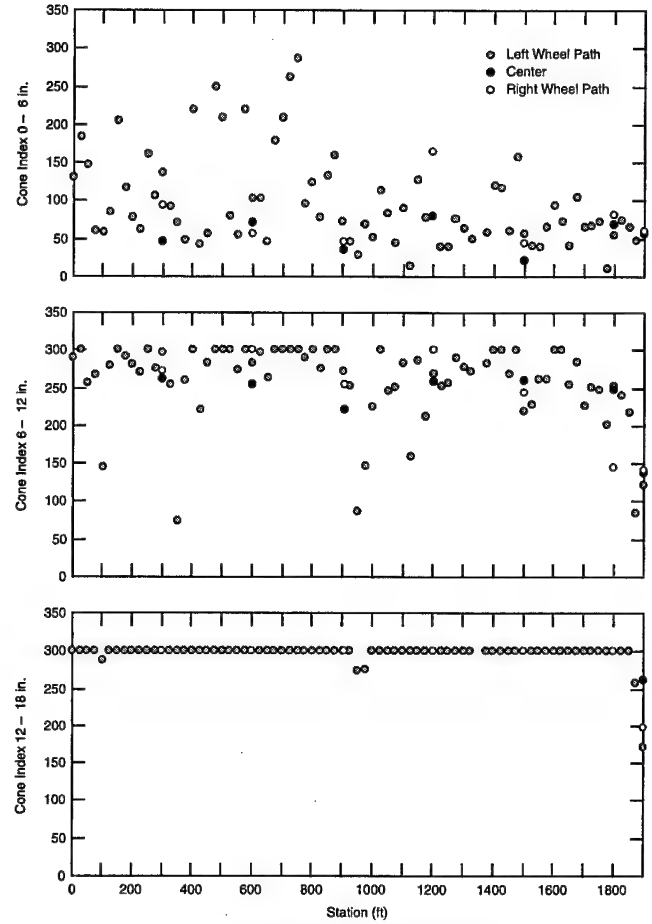


e. Profile.

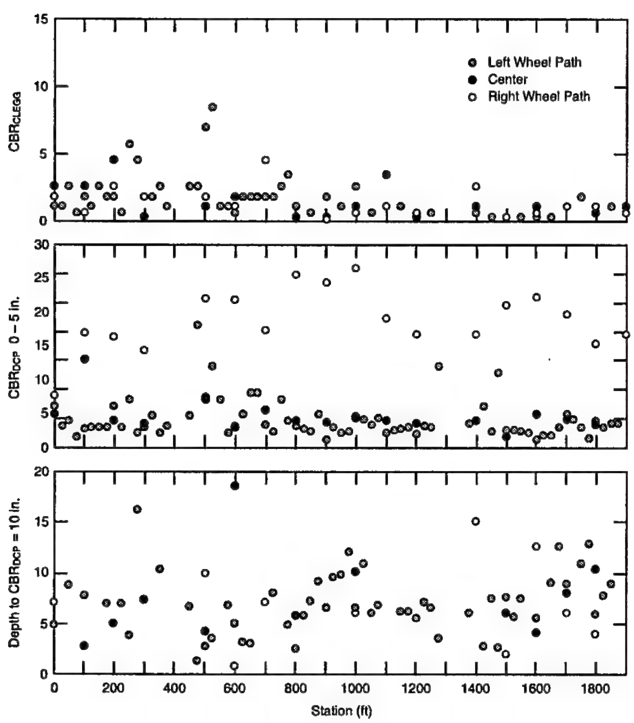
Figure A1 (cont'd).



f. Wooded trail.

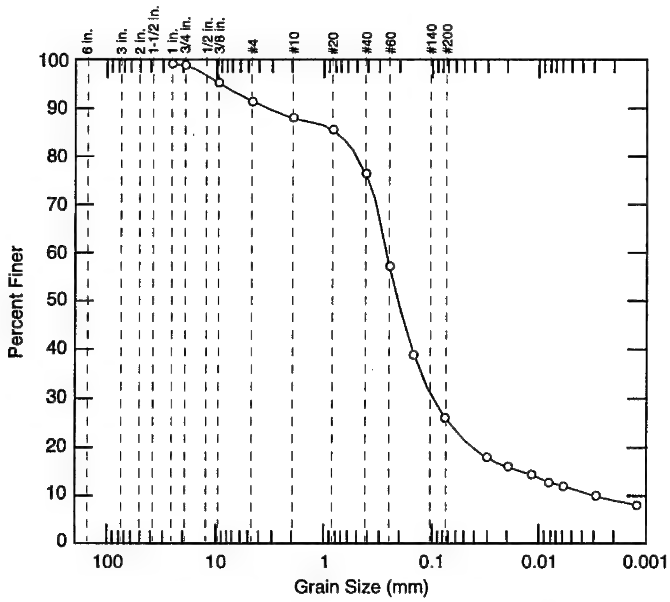


g. Cone index for wooded trail.



h. CBR values for wooded trail.

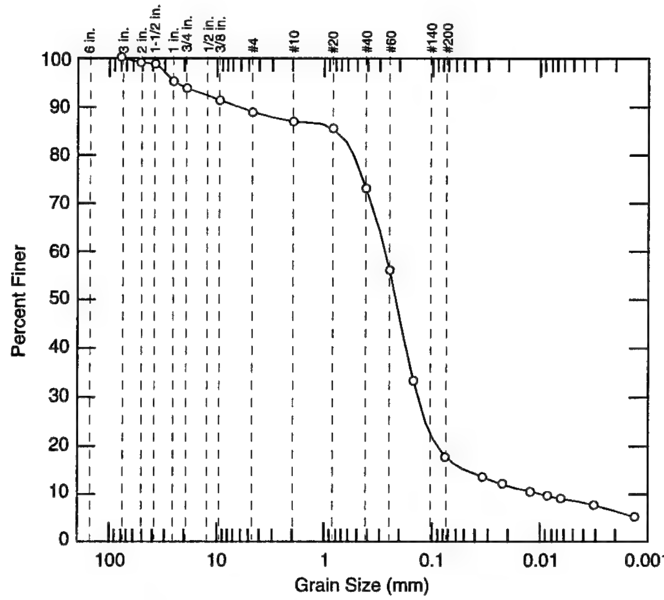
Figure A1 (cont'd). Wooded trail.



	% +3"	% Gravel	% Sand	% Silt	% Clay
o	0.0	7.9	66.0	14.7	11.4

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o	14.7	13.8	0.692	0.263	0.204	0.0987	0.0148	0.0030	12.45	88.1

Material Description	USCS	AASHTO
o Slope Trail	SC	A–2–6

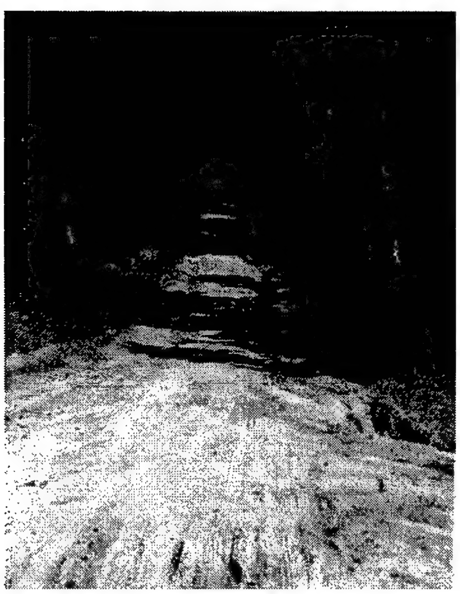


	% +3"	% Gravel	% Sand	% Silt	% Clay
o	0.0	11.1	70.9	9.3	8.7

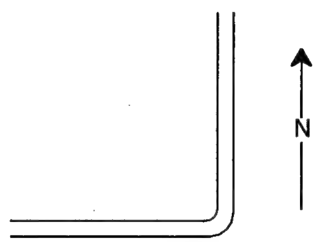
	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			0.785	0.274	0.221	0.137	0.0470	0.0093	7.39	29.6

Material Description	USCS	AASHTO
o Slope Trail, North Slope, East Side	SM	A–2–4

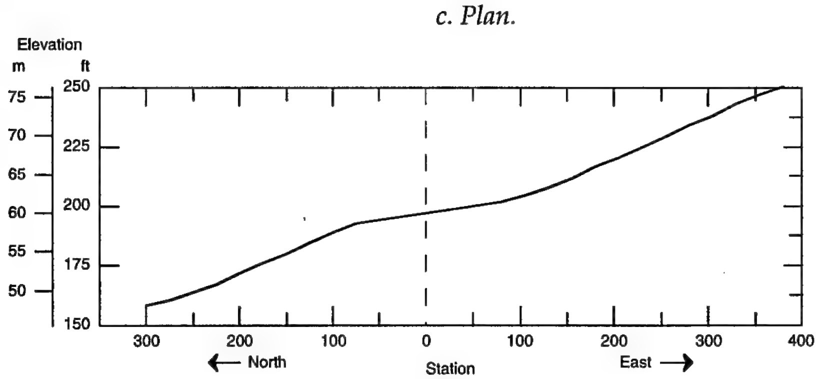
a. Gradation curves.



b. Test site.

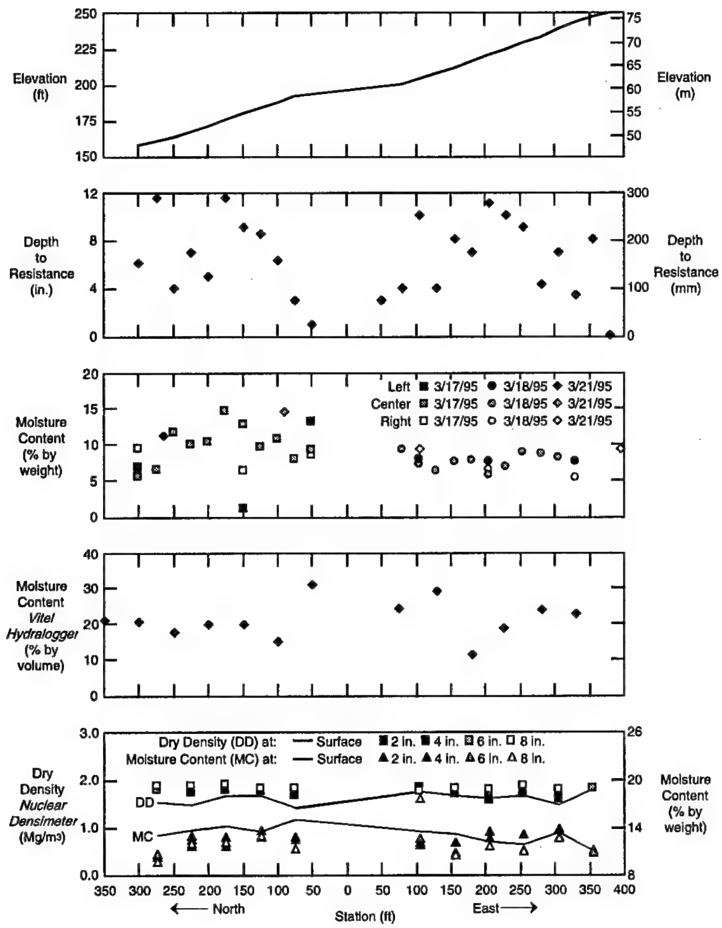


c. Plan.

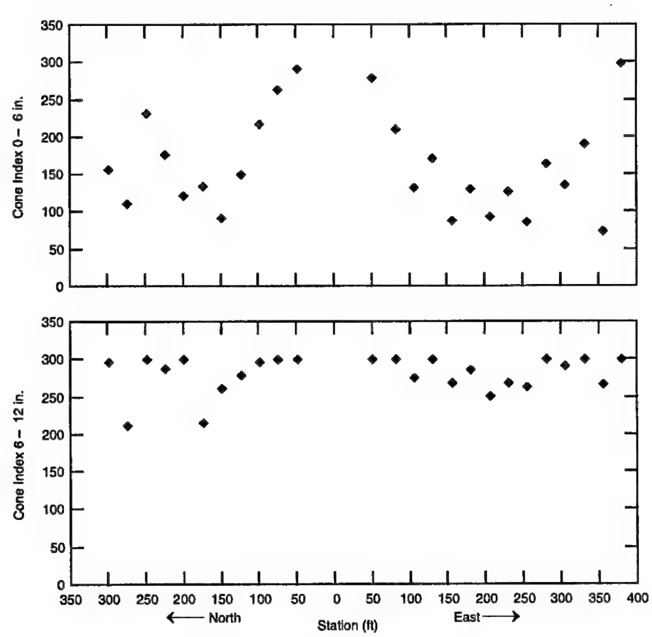


d. Profile.

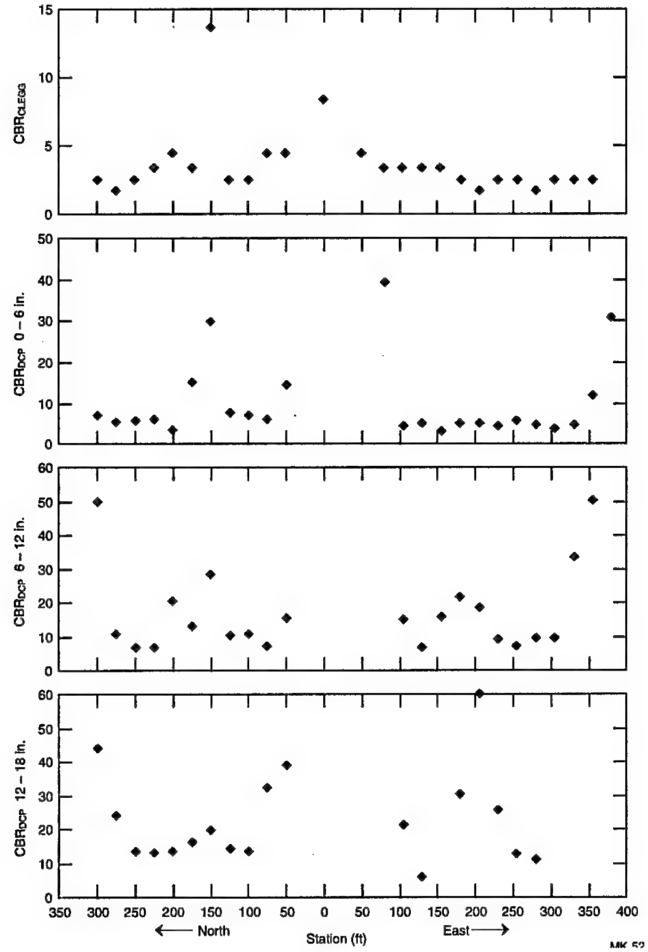
Figure A2. Sloped trail.



e. Slope trail.



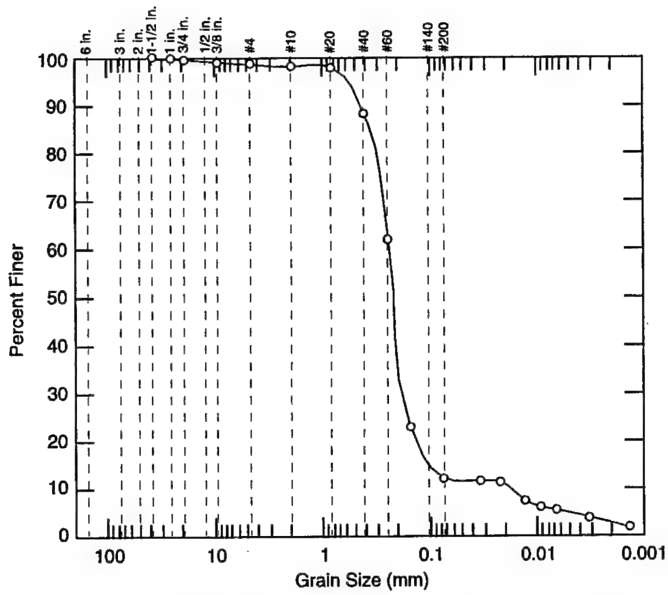
f. Cone index for slope trail.



g. CBR values for slope trail.

a. Test site.

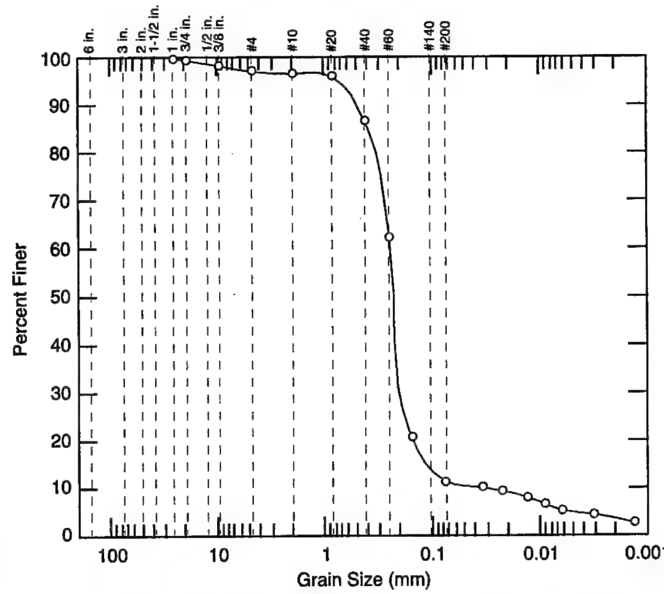
Figure A3. Pentagonal loop trail.



	% +3"	% Gravel	% Sand	% Silt	% Clay
o	0.0	1.5	86.8	6.3	5.4

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			0.376	0.244	0.216	0.168	0.125	0.0167	6.99	14.6

Material Description	USCS	AASHTO
o Pentagon Trail	SP-SM	A-2-4

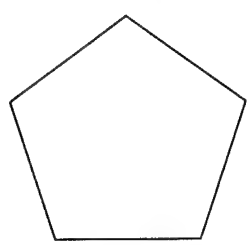


	% +3"	% Gravel	% Sand	% Silt	% Clay
●	0.0	2.4	86.5	6.2	4.9

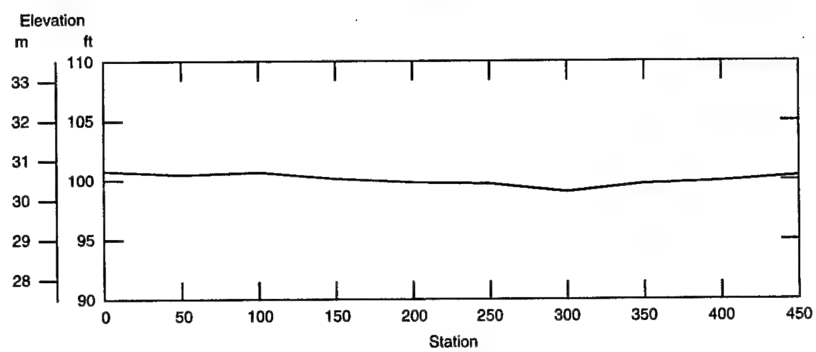
	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●			0.387	0.245	0.219	0.175	0.101	0.0643	1.95	3.8

Material Description	USCS	AASHTO
● Poorly Graded Sand with Silt ● Pentagon Trail Station, Slash Sect., Inside Rut	SP-SM	A-2-4

b. Gradation curve.

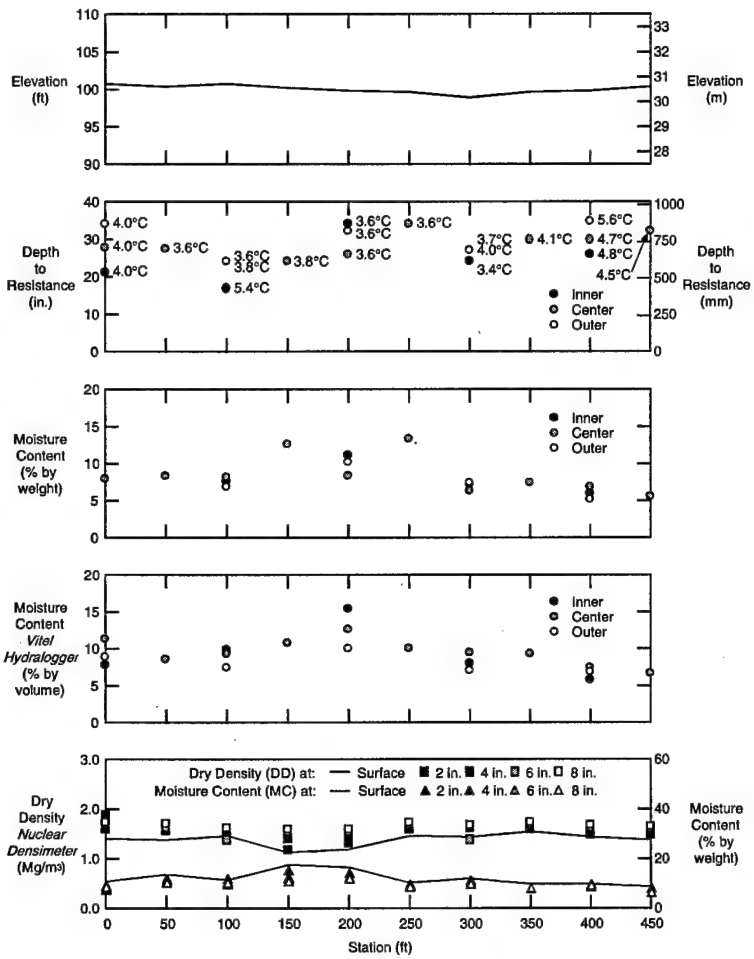


c. Plan.

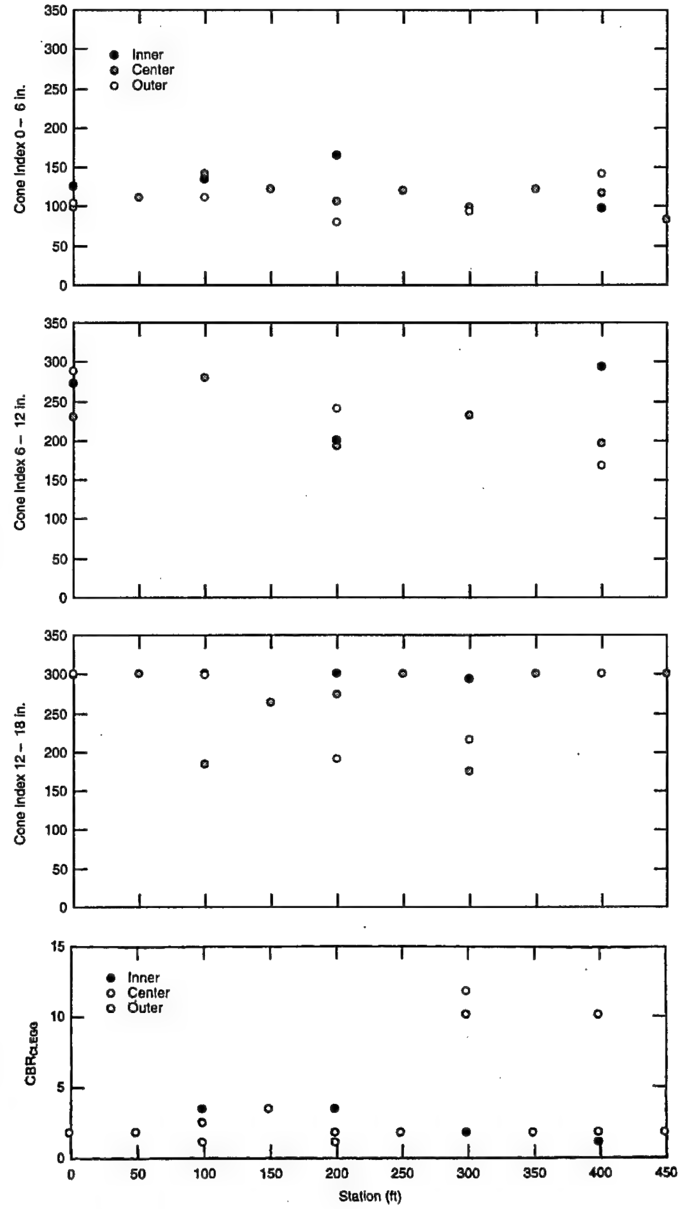


d. Profile.

Figure A3 (cont'd). Pentagonal loop trail.



e. Pentagonal loop trail.



f. Cone index and CBR values, pentagonal loop trail.

Figure A3 (cont'd).

Table A1. Thaw depths on the wooded trail at the end of trafficking (26 March 1995).

		Depth to resistance (cm)/ temp (°C)				
Station	*Test section*	*Left side*	*Left rut*	*Middle*	*Right rut*	*Right side*
				61/ 2.8		
0+00		29/ 3.1	13/4.8	61/ unfrozen	23/ 4.2	10/0.3
1+00						
2+00		18/ 0.2	44/1.8	10/4.5	61/ 2.4	19/ 0.4
3+00		11/ 0.5	24/0.5		61/ 1.6	37/ 1.4
4+00		10/ 0.3				34/ 0.3
5+00		10/ 0.9				32/ 0.5
6+00		10/ 5.5				14/ 5.9
7+00		27/ 1.2				
	Local dip in control sec.		29/ 4.4			
8+00		27/ 0.3	5/4.9		5/not measured	
9+?	Transition: Geonet/ Tire chips		47/1.6			
10+0		61/ 1.4			14/ 0.3	
11+00		18/ 0.3			28/ 0.3	
12+00		8/ 0.2			14/ 0.3	
13+00				5/ 1.4	5/ 0.2	
14+00		11/ 0.7			14/ 0.5	
15+00		20/ 0.3			20/ 0.2	
16+00		5/ 0.4				61/ unfrozen
16+00						
17+00						15/ 0.8
18+00			31/0.4		46/ 0.9	

APPENDIX B: LABORATORY TESTS ON SOILS—PROCEDURE AND RESULTS

LABORATORY SOIL TESTS

A variety of laboratory tests were conducted on Fort McCoy soil samples. The samples were separated using a no. 4 (4.75-mm) sieve and oven dried before testing. Tests and corresponding results are summarized in Table B1. Compaction test using ASTM Standard D 698 Method C and California Bearing Ratio (CBR) test using ASTM Standard D1883 were also performed on the Fort McCoy samples (ASTM 1985). There were difficulties when performing tests at wet of optimum moisture content, which is typical of these types of soil:

- When performing the CBR test, water leaked out of the bottom of the mold, therefore the moisture content on the top and bottom of the sample were different.
- When compacting the last layer of the mold there were surface irregularities due to the consistency of the soil. Figure B4 shows a typical grain size distribution for a soil sample, and Figure B1 shows graphs of moisture content vs. densities and CBR values of all the samples.

The remolding cone index (CI) test for sands with fines was performed following TM 5-33/ AFM 86-3, Vol. II, Chapter 9, *Soils Trafficability*. The soil was oven dried before conducting the test. Using a 152.4-mm (6-in.) mold, material passing 19.0-mm (3/4-in.) sieve was compacted at lower than optimum density and moisture content, then soaked to establish the in-situ moisture content and density. A sampling tube approximately 5 cm (2 in.) in diameter was inserted into the mold and the soil sample was extracted then ejected into the remolding cylinder. The soil strength of the sample was determined using a cone penetrometer to measure the original and remolded CI as the base of the cone penetrate the soil sample at each successive inch to a depth of 10 cm (4 in.). The original CI readings were measured first and the remolded CI readings were then measured after applying 25 blows with the drop hammer from a height of 15 cm (6 in.). The ratio of the remolded CI to the original CI is called a remolding index (RI). Because of the soil type, the moisture content and density varied from top to bottom. The samples were not homogeneous and thus they gave nonrepetitive readings. Average RIs are summarized in Table B1.

Table B1. Laboratory tests, locations and results.

Sample site	*Soil classification (ASTM Standard D 2487)*	*Specific gravity (ASTM Standard D 854)*	*Atterberg limits (ASTM Standard D4318)*	*Optimum moisture content (%) (ASTM Standard D 698, Method C)*	*Maximum dry unit weight kg/m³(lb/ft³) (ASTM Standard D 698, Method C)*	*Remolding index (RI)*
Wooded trail station 1+50	SP-SM (poorly graded sand with silt)	2.63	Nonplastic	8.2	1910 (118.8)	3.64
Wooded trail station 8+25	SM (silty sand with gravel)	2.65	1.7 plasticity index	10.9	1934 (120.3)	0.76
Wooded trail station 16+50	SM (silty sand)	2.65	Nonplastic	11.4	1900 (118.2)	1.10
Pentagon trail	SP-SM (poorly graded sand with silt)	2.64	Nonplastic	8.4	1915 (119.1)	
Slope trail	SC (clayey sand)	2.71	Nonplastic	8.8	2069 (128.7)	
Aggregate	GP-GM (poorly graded gravel with silt and sand	2.80	Nonplastic			

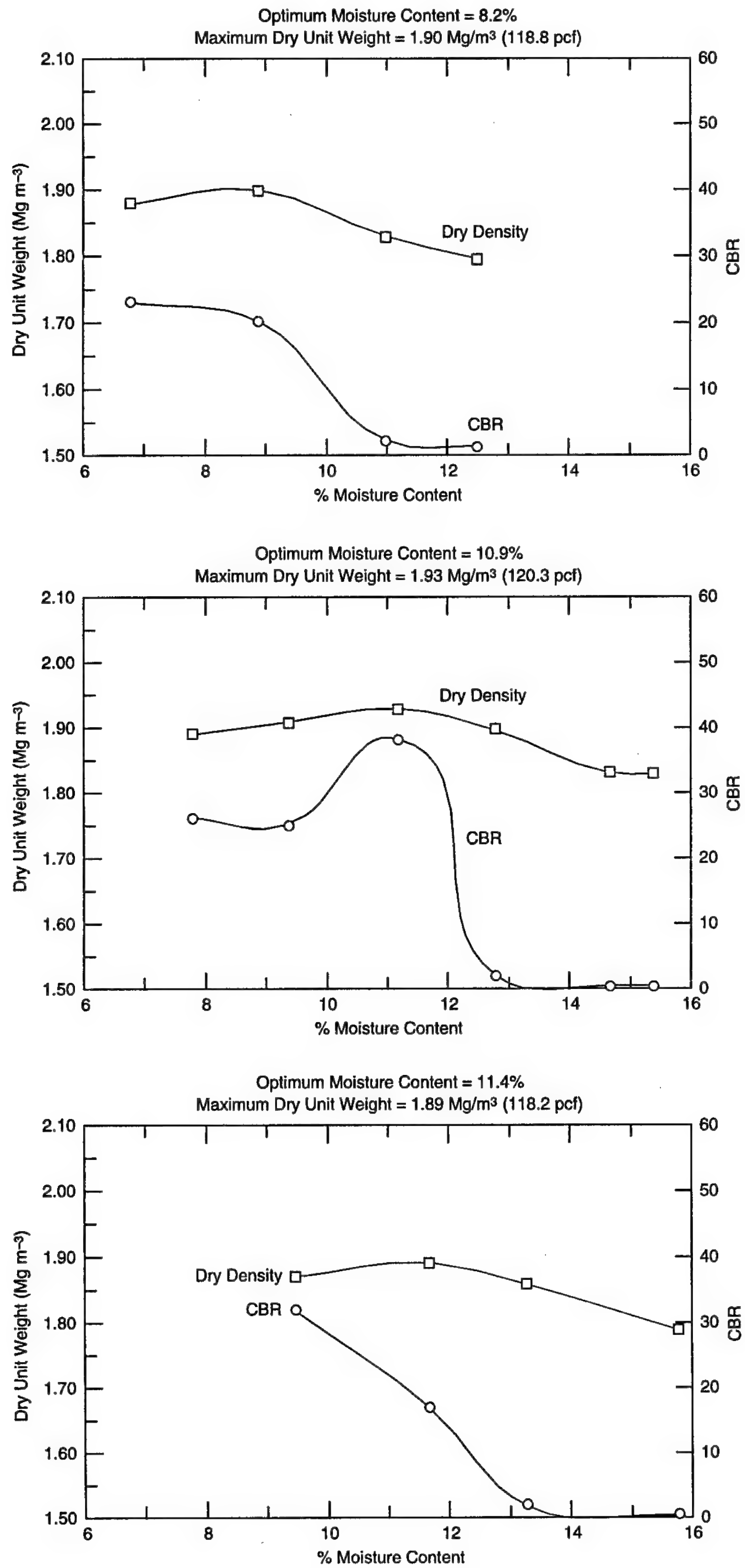


Figure B1. Wooded trail stations 1+50 (top), 8+25 (middle), and 16+50 (bottom).

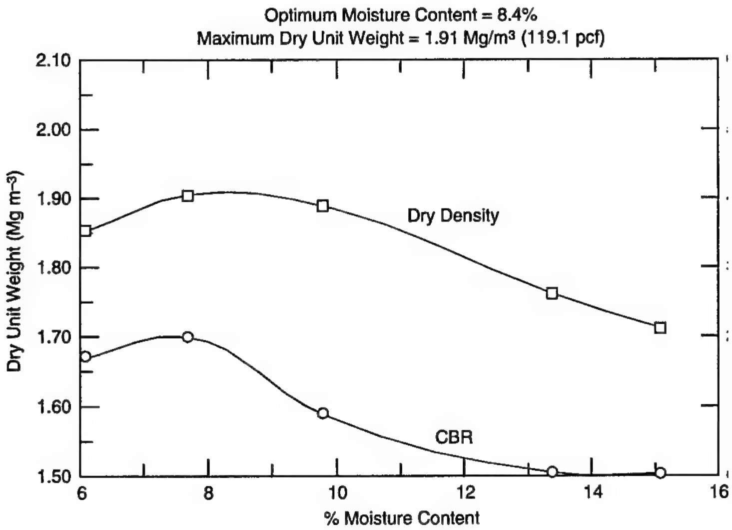


Figure B2. Pentagonal loop trail.

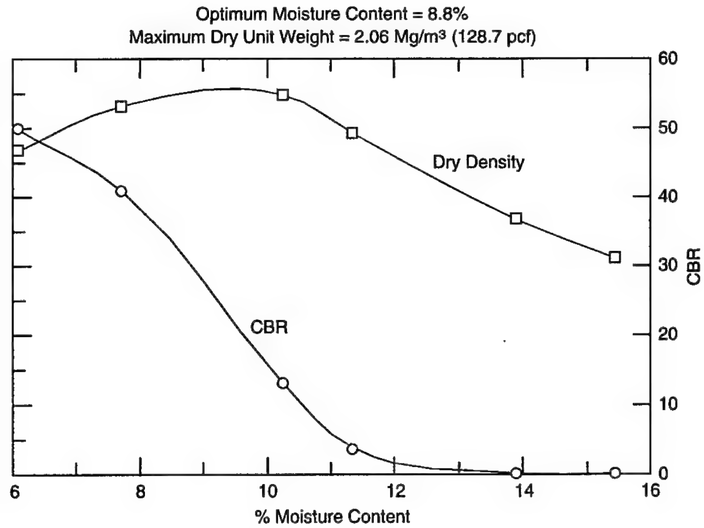
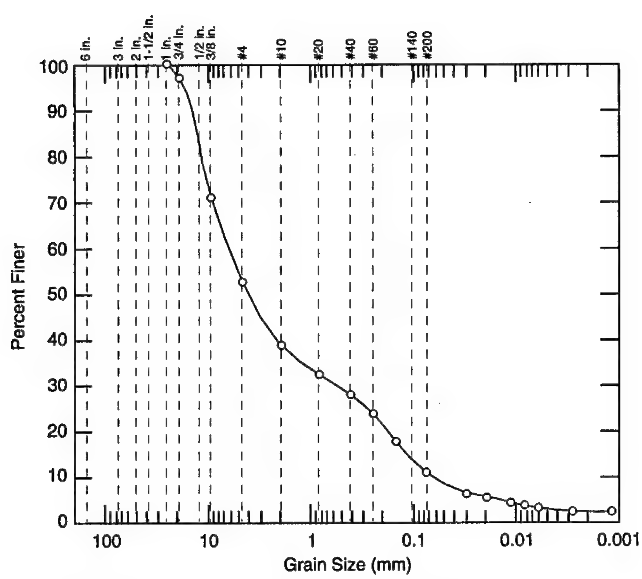


Figure B3. Slope trail.

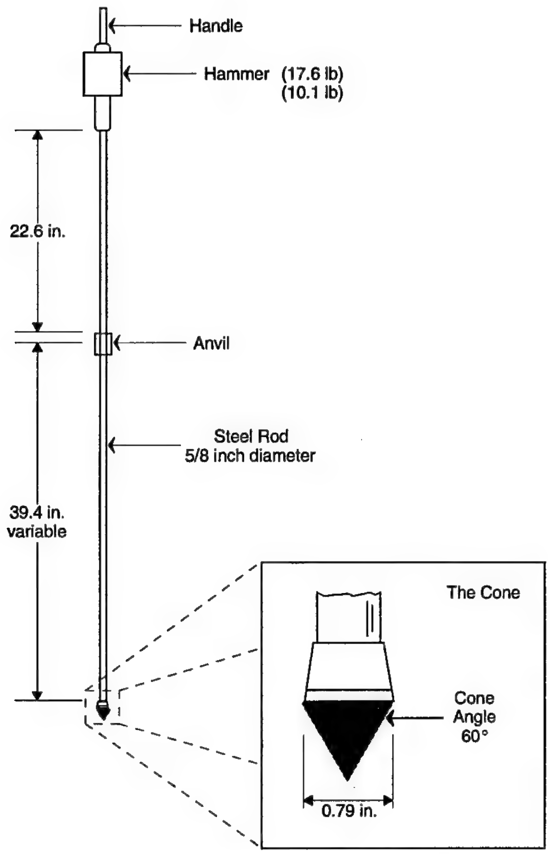


	% +3"	% Gravel	% Sand	% Silt	% Clay
o	0.0	47.0	41.7	8.3	3.0

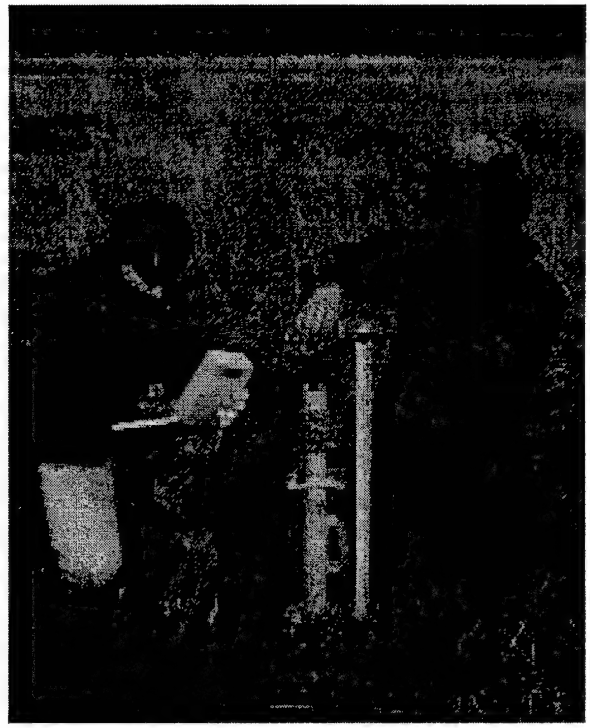
	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o	none	none	13.9	6.38	4.07	0.512	0.112	0.0595	0.69	107.2

Material Description	USCS	AASHTO
o Gravel	GP-GM	A–1

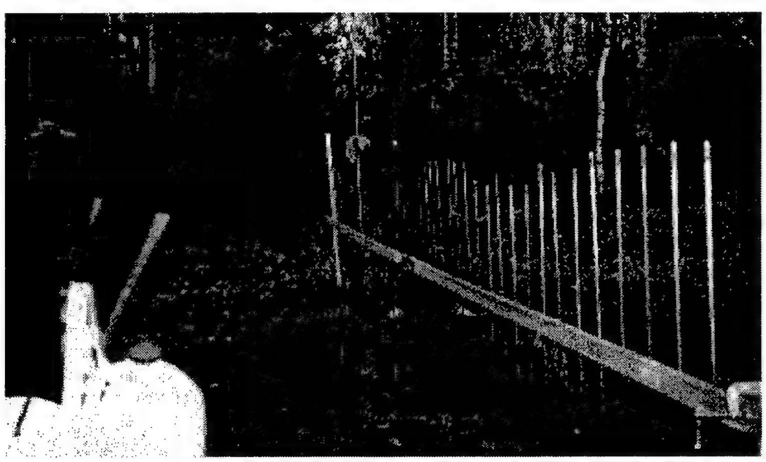
Figure B4. Typical grain size distribution.



a. Dynamic cone penetrometer (DCP).



b. Clegg impact tester (CIT).



c. Measuring rut depths manually.

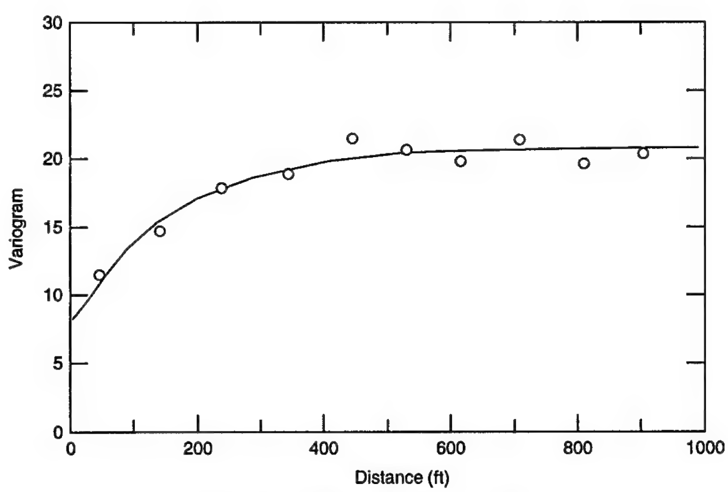
Figure B5. Sampling and testing devices.

VARIOGRAM FUNCTION

The variogram function is a mathematical model that expresses the statistical variance as a function of separation distance. If 10 Clegg impact tester (CIT) readings were taken at the same point, there would be very little spread to the data set. Furthermore, this is true whether these 10 tests are conducted at station 1+00, station 2+00 or station 10+00. (Statistically, this spread is measured by variance.) Now we allow a second set of CIT readings to be taken at 3-m (10-ft) separation distances, i.e., one each at stations 0+00, 0+10, 0+20, etc. This time, there will be some small variance. Additionally, this small variance will be approximately the same as the variance for readings taken at stations 0+05, 0+15, 1+25, etc., or at stations 0+08, 0+18, 0+28, etc. The same procedure is repeated for increasingly larger separation distances until the variance becomes somewhat constant in magnitude. Results of this testing procedure are plotted in the form of a variogram where the separation distance is plotted on the x axis and the variance (of the difference) on the y axis. The separation distance at which the variogram levels out, referred to as the "range," indicates the distance beyond which the measured parameter is no longer correlated.

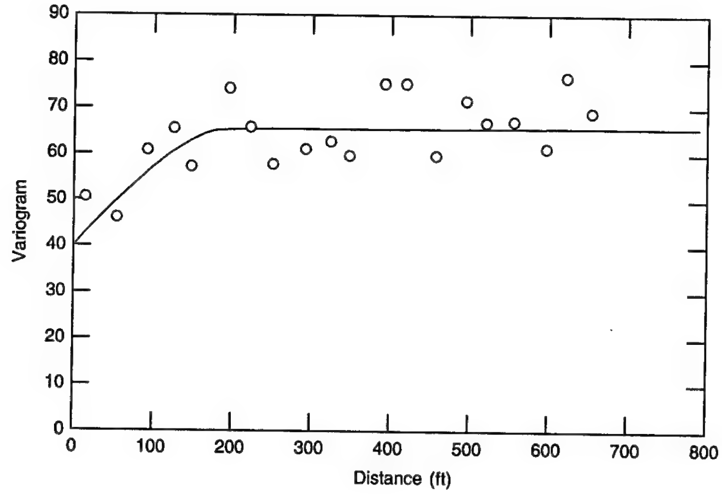
Figures C1a–C1d show variograms with correlation ranges of 125, 67, 61, and 40 m (410, 220, 200, and 130 ft) corresponding to gravimetric water content, ln CBR_{CLEGG}, ln thaw depth, and percentage of initial standing water. As stated above, these variograms indicate the distance over which any one parameter is correlated. The water content variogram, for instance, shows that wooded trail water contents are correlated for up to a distance of approximately 125 m (410 ft).

A variability analysis showing the influence of subgrade variability on test section performance at Fort McCoy is outlined in Kestler (1996). Geostatistical and Statistical software used include GEO-EAS (Englund 1992) and *Statgraphics* (Manugistics 1994).

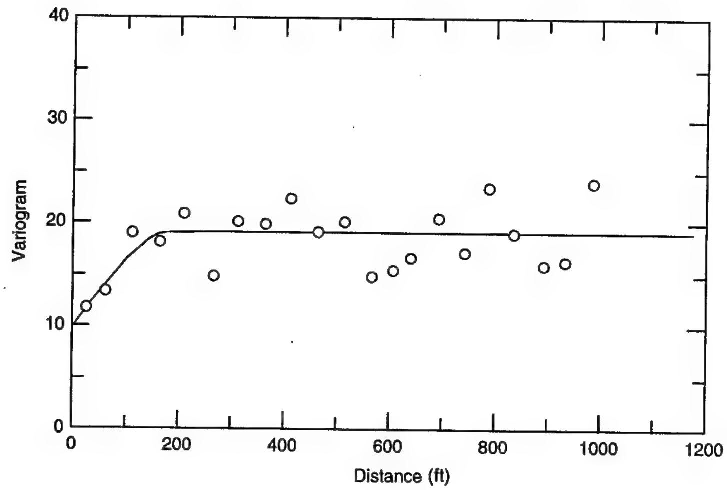


a. Gravimetric water content.

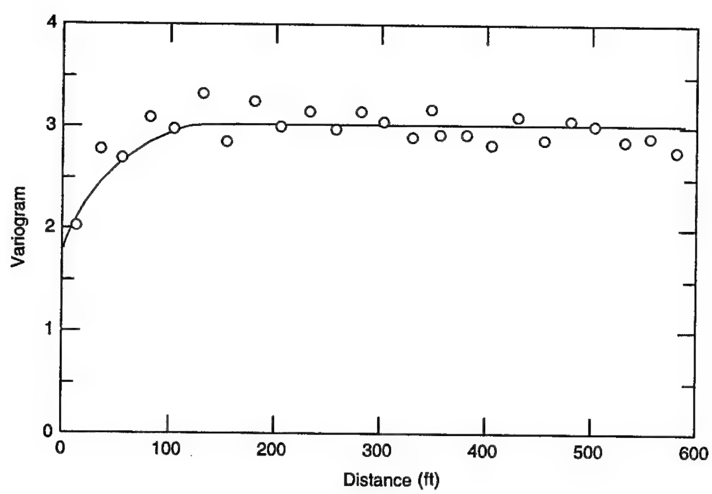
Figure C1. Experimental variogram—wooded trail subgrade.



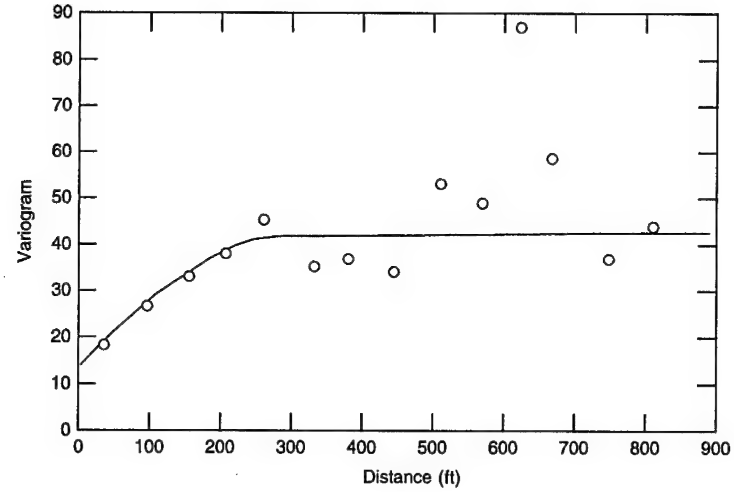
Variogram
Distance (ft)



Variogram
Distance (ft)



Variogram
Distance (ft)


Variogram
0
10
20
30
40
50
60
70
80
90
0
100
200
300
400
500
600
700
800
900
Distance (ft)

BLANK

APPENDIX D: PRETEST OF GEOSYNTHETIC MATERIALS

Objectives

There were three objectives in conducting the pretest:

1. To rank the geosynthetics' performance with respect to resistance to damage by tank traffic.
2. To "measure" the improvement to damage resistance by tank traffic due to covering geosynthetics with 15 cm (6 in.) of "fill."
3. To rank the geosynthetics' performance with respect to reinforcement of weak soil to improve trafficability. This was a secondary objective, and we knew that achieving it would be difficult at the time we planned the tests; indeed this turned out to be correct.

Date, location, and site conditions

The pretests were conducted on 16 and 17 March 1995. The soil was fine sand in a "loose" state; it had frozen overnight (on 16 March), and had relatively low moisture content on the surface. It was completely thawed at the time of construction, was rutted, and was easily rutted more by construction traffic.

Test sections

Two test sections were constructed. One consisted of "bare" geosynthetics lying on the ground. The other was the same geosynthetics covered with 15 cm (6 in.) of bank run gravel available on base. For both test sections, six different geosynthetic products were laid in 6.1-m (20-ft) lengths in a row on top of the sandy soil, with about 1.5-m (5-ft) spacing between the ends. The test sections were parallel to each other with about 1.2 m (4 ft) between them. The bare geosynthtic products were given numbers 1 to 6, and were laid north to south from number 1 to 6; the covered products were laid south to north from number 1 to 6. The products numbers were (see Table 2 in main body of the report for the project description) as follows:

1	2	3	4	5	6
GTF 300	Polyrock	Geogrid overlain with TS 1000	Double-sided geonet	TS1000	Geogrid

Test section construction

No site preparation was done, and material was placed on rutted sandy soil, having ruts up to 20 cm (8 in.) deep. The surface was very uneven. The materials were very easy to lay out; most could be carried by hand by two people. The double-sided geonet was an exception—it required a SEE to be moved around.

When the gravel was placed, the dump truck drivers were asked not to drive directly onto the materials. They found this difficult to do and short sections of the products (up to 1.2 m [5 ft] long) were driven on anyway. However, there was no apparent damage.

Grading of the thin layer of gravel resulted in visible damage to some materials—the center of the material was nicked and the edges were exposed. The grading damage made it obvious that driving dump trucks on the sections with little cover caused the materials to deform such that they were depressed into the wheel tracks and bulged upward in between the wheels. Post-construction excavation of trenches across the material showed that the actual cover thickness ranged from 2.5 to 20 cm (1 to 8 in.).

Grading damaged geosynthetics, as follows:

Material	*Damage*
Double-sided geonet	Small (19-cm^2 or 3-$in.^2$) pieces of geotextile were ripped off of the netting in two places.
TS 1000	Abraded in the center, about 32 cm^2 (5 $in.^2$). Blade did not cause hole to form.
Geogrid	Was cut on the NE corner.

Test procedure

The tests consisted of three procedures—tank driving (trafficking), followed by tank braking, and then tank pivoting. The condition of the geosynthetics were assessed after each procedure was completed. For the trafficking, the tank was driven over each test section 10 times. Five passes were at 11 to 16 km/hr (7 to 10 mph) and five passes were at 24 to 27 km/hr (15 to 17 mph).

In the brake tests, the tank was traveling at 24 km/hr (15 mph) when the brakes were applied. They were applied just as the front of the tank reached the edge of the geosynthetic.

After the brake test, pivot tests were conducted. In these tests, the tank was driven onto the test section so that it was centered. Then the driver did a 180° turn by holding one track stationary.

Results

Trafficking

Geosynthetics placed on the surface survived 10 tank passes with no apparent damage. Materials with flexural stiffness (the double-sided geonet, the geogrid and the geogrid-geotextile combination) bunched up into "high" bunches, stretching across the width of the material perpendicular to the direction of traffic. The geogrid covered with TS 1000 bunched up the highest at 46 cm (18 in.) high. The GTF 300 (woven slit film) slid around on the soil surface, and the TS 1000 deformed neatly into tracks made by the cleats in the tank treads. Since all bare materials laid on the surface performed well for the trafficking and braking tests, these tests were not conducted on the materials covered with gravel.

Braking

Except for a few geogrid strands being broken, no damage to any products placed on the surface occurred.

Pivoting

Nothing survived the pivot tests on the uncovered materials; every product sustained rips and tears across the width of the sample. Furthermore, the geogrid and the TS 1000 became entangled in the tank sprockets and gears that drive the tread, and required considerable time to remove.

For materials covered with gravel, Polyrock was the only product that survived the pivot tests. It pulled out of the soil (and was thus rendered useless until repositioned), but it did not break or tear.

Product selection for further testing

Based on the results described above, the Polyrock and the double-sided geonet were selected for further testing.

APPENDIX E: OBSERVATIONS MADE DURING AND AFTER TRAFFICKING ON SLOPED, WOODED, AND PENTAGONAL LOOP TRAIL TEST SECTIONS

Table E1. Overall trail trafficking performance evaluations.

Test section	*Performance and general observations*	*Advantages*	*Disadvantages*	*Potential future development*
30 cm (12 in.) of gravel overlying nonwoven geotextile (wooded trail only, 0+50 to 1+00).	Developed slightly less deep ruts than the adjacent section with gravel fill only.	1. Geotextile is commercially available, inexpensive, and can be placed by hand. 2. Army guidance available. 3. Time consuming if gravel must be hauled a long distance.	1. Gravel may not be available. 2. Personnel are briefly exposed during placement of geotextile.	The modification of construction equipment to mount rolls of geotextile on the front would make the placement of the geotextile more expedient and safer. These modifications have already been done in the private sector.
Gravel fill (wooded trail only, 1+00 to 1+50). Depth varied.	This section generally performed well except for dip in trail at 1+00. The trail width increased from 4.3 to 5.5 m (14.5 to 19.3 ft) during tank trafficking.	1. Troops are familiar with repairing ruts by filling and blading. No new training is required.	1. Gravel may not be available. 2. Time consuming if gravel must be hauled a long distance.	
Control (wooded trail, 1+50 to 2+50).	Ruts were deepest at local dips in the trail. The tank bellied out repeatedly over a 30-ft length in this section. Chunkwood was added to ruts at HEMTT pass 25.			
Control (sloped test section only).	Rutting to bedrock provided a good travel surface. Notably more trafficable for the tank than the adjacent slash test section.	1. If bedrock is located close enough to surface (i.e., less than 6.3 cm (4 in.) no treatment may be needed.		
Uni-Mats	There were some broken cross members and split boards after the tank trafficking. Very slippery when wet. HEMTT could not start from stop on the slope, and tank slid on downhill stop.	1. Very durable. 2. Material is available through GSA.	1. Labor intensive for placement. 2. Special equipment is required (forklift with long/extended forks). 3. Limited number of sites for which it is well suited, i.e., it is best suited to straight roads on flat or uniformly sloping sites. 4. May be dangerous on slopes due to slipperiness when wet or icy.	Good way to reinforce corners for tank trails; otherwise, probably best suited to relatively flat or uniformly sloping sites. Slipperiness when wet should be addressed. A tractive coating such as sand or gravel with glue could be added to the surface. Anchoring system may be needed on slopes.
Tire mats	Held up well in all tests except tank cornering. Tank cornering caused displacement and damage to the mats. Trafficking caused them to move together on the wooded trail because they were not centered under the track.	1. Very durable—seems suitable for tank use on straight sections. 2. Material is commercially available. Could be added to GSA schedule.	1. Labor and equipment intensive for placement. (Personnel exposed during the operation.) 2. Cannot sustain tank cornering. 3. Some slippage on the soil during tank stop.	A lighter, easier-to-handle product would be much more expedient to place. Better anchoring might be needed for use on slopes and/or in extremely wet soil with tank trafficking.
Polyrock	Damaged by the dozer during construction. It lasted for 20 tank passes on the wooded trail without significant damage; but, at 30 tank passes, it had "failed." The steel cables used to fasten the ends of the geotextile held up well.	1. Material is light and easy to handle. 2. Commercially available. 3. Reduced surface erosion of topsoil during raining and trafficking on the slope.	1. Tanks and dozers (i.e., tracked vehicles) easily damage the material. 2. No effective means to anchor without gravel or other fill.	1. A means of anchoring that does not damage the material should be developed for placement on the surface of the frozen ground so that reinforcement can occur as the ground starts to thaw and deform.

Table E1 (cont'd).

Test section	*Performance and general observations*	*Advantages*	*Disadvantages*	*Potential future development*
	Less rutting than the control section. On slopes it bunched and slid downhill.			2. Steel reinforced material could be developed. 3. The modification of present construction equipment to mount rolls of geotextile on the front would make the placement of the geotextile more expedient and safer. 4. May need to anchor in ruts with granular fill as described below.
Trevira w/gravel on top placed to conform over existing ruts.	This technique was tested only for the HEMTT trafficking on the wooded trail and it performed well. At the end of trafficking, ruts at both ends of the test section were notably deeper than over the test section.	1. Geotextile is commercially available, inexpensive, and can be placed by hand. 2. Minor modification to Army's current practice required to implement. 3. May use less gravel than needed to "fill" the test section. 4. Can be easily placed with available equipment and some labor.	1. Some manual labor required to place the geotextile and fill. (Personnel exposed during the operation.)	The modification of present construction equipment to mount rolls of geotextile on the front would make the placement of the geotextile more expedient and safer. A concrete-mixer type funnel mounted on one of the vehicles could help direct fill to the side trenches during placement.
DS Geonet	On the wooded trail, the tank damaged (sliced) the product, and the biggest ruts developed over the damaged area. Where the material wasn't damaged, the ruts were 17.8 to 22.8 cm (7 to 9 in.) instead of 34.3 cm (13.5 in.) on the damaged portions. HEMTT causedslightly more damage to this test section on the wooded trail. On the slope, there was a significant problem with this product sliding downhill; but it did provide good protection from rain and traffic.	1. The geonet is commercially available. 2. It can be placed with the use of equipment and manual labor. 3. Provided protection of subgrade during raining and trafficking on the slope.	2. Some manual labor required to place the geonet. (Personnel exposed during the operation.)	This material falls between the tire mats and lightweight geotextile both in terms of ease of construction and performance. The added stiffness of the geonet is definitely helpful in preventing rut formation. Some variation of this product and an anchoring technique should be further developed for military use.
Tire Chips	Good traction, even on slope. HEMTT threw chips during first few passes on slope (caution: flying chips).	1. Very durable, excellent for tank use. 2. Uses a waste material. 3. Requires little manual labor. 4. Good traction.	1. Steel poses a significant risk of puncturing rubber tires, and boots of people walking on it. 2. Potential hazard if it catches on fire. 3. Some states prohibit use if beneath seasonal high groundwater table. Additional research required.	A protective layer for rubber-tired vehicle and foot travel on top of the tire chips may help; or, the development of a product without the wires.

Table E1 (cont'd). Overall trail trafficking performance evaluations.

Test section	*Performance and general observations*	*Advantages*	*Disadvantages*	*Potential future development*
Tire chips with geotextile (wooded trail only).	Post-test excavation showed that the geotextile did not extend across entire width of the wheel base of the tank or the HEMTT. Thus, it is not valid to compare tire chips with and without a geotextile separator.			Wider geotextiles would be better.
Slash	Test sections were bumpy, which caused vehicles to slow down and had poor traction, on the slope. Level section on wooded trail built with smaller diameter branches and logs performs well. Protruding branches posed risk of damage to HEMTT undercarriage and got stuck in tank track.	1. Uses locally available material, can be truly expedient if slash is available.	1. Intense manual labor required. 2. Appears not to be suitable for tank travel under most circumstances. 2. Walking is difficult (for ground troops). 3. Easy to booby trap. 4. Need a source of slash.	Wider geotextiles may help. Laying no more than 3-in.-diam. trees posed less damage to the vehicles, and placing some materials lengthwise in the ruts appeared to help. (The trees would make good beams and spread the load along the wheel path.) Perhaps the best alternative is close to the corduroy roads already used by the military.
Slash with geotextile (wooded trail only).	Post test excavation showed that the geotextile did not extend across the full width of the wheel base of the tank or the HEMTT.			
Chunkwood	Good traction, even on slope.	1. Material is environmentally sound. 2. It can be placed and bladed with standard equipment. 3. Good traction.	1. Need a local source of wood. 2. Need development of a reliable chunker.	Need development of a reliable chunker.
Portable wood mats (wood pallets)	Cottonwood pieces broke during HEMTT trafficking on the slope. The tank broke these during slope trafficking, but they still provided traction and prevented rutting. Slide on the slope during HEMTT trafficking (must be 3 mats).	1. Can be constructed off-site, then transported to road or trail.	1. Not well suited to tank trafficking on slopes.	Development of guideline about what wood is strong enough to use (e.g., cottonwood is not suitable).
Chunkwood wrapped by geotextile to form a "pillow"	Developed on a corner near a ponded area. This was repaired by wrapping chunkwood with geotextile, then placing chunkwood on top of the geotextile. This performed very well during the HEMTT trafficking.	(See chunkwood comments above.) (See geotextile comments above.)	(See chunkwood comments above.) (See geotextile comments above.)	(See chunkwood comments above.) (See geotextile comments above.)

Table E2. Observations made during and after trafficking on the sloped trail test sections.

Test section	Rut depth after trafficking	No. of passes	Comments
Chunkwood	HEMTT: 6–7 in.		Uniform rut depth
	avg. range is 0–13.5 in.	HEMTT–10	Ruts are uniform depth along whole test section
		HEMTT—all uphill passes	HEMTT slipped, then excavated chunkwood by spinning the wheels.
		HEMTT Start/stop	Good traction.
	M60: 6–11 in.		Wood chunk-mud mixture in the bottom of the rut. Left rut is in the subgrade.
		M60–10	Left rut is 11 in. deep, and subgrade is exposed.
		M60–25	Left rut is at top of subgrade.
Tire chips	HEMTT: 7–9 in. avg., max 18 in.		Four-in. ruts located inside of 5-ft-wide by 12-in.-deep ruts. Very uniform depth.
		HEMTT—first few passes	Tire chips "flying"
		HEMTT–25	Soil exposed in the left rut.
		HEMTT–32	Tire chips are 7 in. thick in the left rut.
		HEMTT–34	Tire chips are 6 in. thick in the right rut.
		HEMTT start/stop	Six-in. ruts located in the bottom of wider ruts. The 6-in. ruts go into the subgrade.
			Good traction.
	M60: 13–18 in.	M60–25	
			Left rut is at top of subgrade.
Slash	HEMTT: 2–6 in.		Measured from the soil surface to bottom of rut. The test section is very bumpy, with up to 3 ft of elevation difference along a 15-ft length. Many branches broken by trafficking. Many small branches appear likely to damage undercarriage of vehicle. HEMTT slipped—this is a very slippery test section. Branches twisted, and were gradually moved to a parallel position in the ruts.
		All HEMTT passes	Vehicle had great difficulty starting on this test section.
		HEMTT start/stop test	A large branch forced the track to climb the sprocket, and tank almost threw a track.
		M60 (number of passes was not recorded by observer)	Only 6 in. and larger diameter trees, placed perpendicular to soil, provide good support. Poor traction caused the HEMTT to "dig" very deep ruts in the chunkwood section. Trafficability may have been worse on a long test section.
		M60–all	
Control-N	HEMTT: 10 in. avg.		Ruts reach to bedrock.
		All HEMTT passes	Base soil provides good traction. (Surface mud is pushed out of the way by vehicle tires.)
	M60: 11 in. max		
		M60–26	Starting with this pass, the base soil in the bottom of the ruts is "semi-frozen" and therefore more stable.
		M60–most	Tank performs well on "hard base."

Table E2 (cont'd). Observations made during and after trafficking on the sloped trail test sections.

Test section	*Rut depth after trafficking*	*No. of passes*	*Comments*
Wood mats	HEMTT: see comments		Eight out of 16 cross-piece boards were broken on the left. One out of 19 cross-piece boards were broken on the right. Slid downhill about 2.5 ft.
		HEMTT–2	Nine boards are broken, and mats are sliding apart.
		HEMTT–10	Cottonwood boards are breaking.
		HEMTT–13	One mat broke and was pushed outside of wheel path.
		HEMTT–18	Had to move wood mats on right side about 2 ft toward the centerline. (Cottonwood are the only boards that are broken.)
	M60: see comments		The mats are broken up and forced into the ground with soil forced up between boards.
			Some boards broke.
		M60–1	Broken boards are sticking up and mats are rapidly deteriorating. They are also sliding outward.
		M60–10	
			Small amount of the mats break off with each pass.
		M60–all	
Uni-Mats	HEMTT: see comments		Slipped downslope about 6 in. total.
		HEMTT—first few passes	Very slippery.
		HEMTT–40 to 50	Extremely slippery.
		HEMTT start/stop test	HEMTT could not start from a stop.
		M60–24	Slightly slippery.
		M60–all	Slight deterioration with each pass. Nails gradually worked loose (or were pulled up by tank tracks) and protruded.
		M60–start/stop	Tank slid significantly on downhill stop, but mats did not move.
Tire mats	HEMTT: see comments		Looks indestructible, there are 8- to 10-in. ruts at the end of the section on top of the slope. Slipped downslope about 6 in. total.
			Performed well.
		HEMTT–all	
	M60: see comments		Performed well, anchoring of some sort may prevent pile-up on downhill stop.
			No marked weakening or movement of tire mats. Traction excellent.
		M60–24	A wire holding tires together was noted to be broken.
		M60–30	
		M60–start/stop	
			On downhill stop, tires piled up—indicates need for anchoring. Another broken wire found.

Table E3. Observations of test section performance made during trafficking on the wooded trail.

Test section	*Rut depths after trafficking (left/right)*	*No. of passes*	*Comments/ observations*
Sta. 0+50-1+00 (12 in. of gravel over geotextile)	M60: 11/0		Deep ruts at the end of the geotextile (1+00). Average depth of ruts is about 8 in. Geotextile is showing for last 6 ft of test section, which ends in a pothole, or dip. Ruts are 3 ft wide.
		M60–25	Mobility has deteriorated from good to fair since pass 10.
	HEMTT: 9.5/8.5		Road at the end of the geotextile is badly rutted (1+00). Thaw depth is 24 in. between ruts, ranges from 4 to in excess of 12 in. in the ruts.
Sta. 1+00-1+50 (Gravel fill)	M60: 12/16		At the end of the geotextile, ruts are 12 in. on the left and 16 in. on the right. Most ruts are less than 5 in. deep. Section looks good. 0.2 ft to frozen ground in the ruts, > 3 ft to frozen ground on the side of the trail. Ruts are 3 ft wide. The trail spread from 14.5 to 19.3 ft during tank trafficking.. Thaw depth is 24 in. between ruts, 4 to greater than 12 in. in the ruts.
	HEMTT: not measured		
Sta. 1+50-3+00 (Control)	M60: 14/13.5		Ruts are deepest in a local dip in the trail. There is a 30-ft length where the tank repeatedly bellied out. Average rut depth is about 12 in.
	HEMTT: 16/18		Average rut depth is 12 in. Ruts are deepest in a dip. The tank bellied out for about a 30-ft length over the dip. 0.3 to 0.8 ft to frozen ground in the wheel path. Thaw depths are greater than 18 in. in both ruts. Chunkwood added to ruts, which were 5 and 6 in. deep.
		HEMTT–25	
Sta. 3+00-3+50 (Control)	M60: 15/16		Average rut depth is about 12 in.
	HEMTT: not measured		
Sta. 3+50-4+00 (Uni-Mats™)	M60: see comments		There are some broken cross members and cracked boards. The north end of the mats spread a total of 18 in. They spread apart by 8 in. on the south end. Overall, they were durable. Boards are lifting up lengthwise and nails are loosening.
		M60–16	Generally holding up well, but spreading apart on the north end with minor changes in tank direction.
		M60–25	
			Thaw depths are 4 in. to in excess of 14 in. on the side of the trail.
	HEMTT 0/6		Very slick. Nails worked loose under traffic loads. When dry, the boards tended to crack.
		HEMTT–all	
Sta. 4+00-4+20 (Fascine)	M60: see comments		Fascine is silted in on the left. Almost all of the pipes near the surface are steeply tipping.
		M60–35	What was observed to be broken PVC pipes were actually pipes tipped at a steep angle.
	HEMTT: see comments		Thaw depths are 4 to 13.5 in. on the side of the trail.
		HEMTT–all	These could not be checked—they were tipped into the mud at a steep angle.

Table E3 (cont'd). Observations of test section performance made during trafficking on the wooded trail.

Test section	*Rut depths after trafficking (left/right)*	*No. of passes*	*Comments/ observations*
Sta. 4+00-5+00 (Tire mats)	M60: 8/8		The mats generally held up well, but they slid together significantly (about 9 in. on south end), where they were on top of the fascine. They were also pushed into the mud from 8 to 10 in. in the tank tracks. Ruts formed in the soil after the tank pushed the mats towards each other, then was in contact with the soil. There is visible water flow in the east (right) rut, draining a small pond on the east, from 4+60 to 4+00 (into fascine). Thaw depth is 0.8 to 1.2 ft in the center of the trail. The tank tends to cause the mats to slide on the soil surface.
		M60–all passes	Some mats are being pushed into the mud.
		M60–25	Thaw depths are 4 to 12.5 in. on the side of the trail.
	HEMTT 10/10		Mats are changing position with every pass.
		HEMTT–25	
Sta. 5+00-6+00	M60: 8/8		The travelway spread out during trafficking from11 ft, 5 in. to 14 ft, 3 in. The cable on the left side is missing.
			The ruts reached to the frost layer. Cable anchors held nicely, but the material (and one cable) ripped off of them.
Polyrock for M60 trafficking			Dozer tore the material before trafficking—the largest tear is of a 5-in. L shape.
		M60–0	Polyrock is bunching up and appears to be pulling loose from the cable anchors.
		M60–2	About a 20-ft-long rip in the geotextile; the tank belly appears to be dragging and therefore ripping the Polyrock.
		M60–20	Polyrock pieces are being ripped out and thrown around by the tank.
		M60–35	
Sta. 5+00-6+00 Non-woven geotextile placed to conform over existing ruts, and anchored with 6 in. of gravel in the ruts.	HEMTT:12/14		Held up well; pulled into ruts on some places. A wider geotextile would probably be better (i.e., could achieve better lateral "anchorage"). Ruts at both ends of this test section are notably deeper than those on the test section. Minimum of 4-in.-thaw depth on the side of the trail. 5.5 in. of thaw measured in rut at 6+00.
		HEMTT–15	Holding up well. Material has pulled into the middle of the trail from the sides. No bunching has occurred.
Sta. 6+00-6+60	M60: 18/24		The travelway spread out during trafficking from 14.5 to 19 ft. Ruts are to the frost.
			Tank is dragging belly in places.
		M60–25	Tank is pushing gravel with its belly.
		M60–30	Tank belly pushes saturated gravel and mud, which fills back into ruts immediately after pass.
		M60–35	At the end of testing, weak areas ("sink holes") still appeared after it was bladed by the dozer.
	HEMTT: 20/25		5.5 in. of thaw measured in rut at 6+00.
		HEMTT–10	Ruts are 15 in. and 12 in.
		HEMTT–15	Bladed by dozer.
7+00-8+25 (Control)	M60: 24/24		Travelway spread 2 ft—from 13 to 15 ft. Pre-existing 7.5-in. ruts were filled with a sand and gravel mixture prior to the start of testing. (Clayey soil.) Tank bellied out for the whole distance of the last few passes.
		M60–18	Tank starting to bottom out.

Table E3. (cont'd).

Test section	*Rut depths after trafficking (left/right)*	*No. of passes*	*Comments/ observations*
	HEMTT: 21/24		At the end of testing, weak areas ("sink holes") still appeared after it was bladed by the dozer.
		HEMTT–1	Significant rutting.
		HEMTT–8	HEMTT is bottoming out.
		HEMTT–15	HEMTT got stuck—could not measure rut depths. Bladed with dozer
		HEMTT–18	18-in. ruts.
		HEMTT–25	Three 5-ton dump truck loads of chunkwood added.
		HEMTT–26	HEMTT drove off of trail and got stuck. Dozer bladed the section.
		HEMTT–27	17-in. ruts.
8+25-9+10 (DS Geonet)	M60: 13.5/13.5		Travelway contracted 1 ft—from 13 ft to 12 ft. Pre-existing 6.5-in. ruts were filled with a sand and gravel mixture (on top of the geonet) prior to the start of testing. Widest rut is 3 ft wide. Material is damaged on the sides of the rut in several places.
		M60–10	Tank has worked fill out of the ruts.
		M60–12	Material is bunching.
		M60–13	Tank caused 15-in., 4-in. and 3-in. tears on the material that is in the left side of the existing rut. Raveled left edge at station 8+40.
		M60–14	6.5-ft tear in left rut at 8+25
		M60–23	9.0-ft tear at 8+75 (right rut) , 5.0-ft tear at 9+00, right and 3.0-ft tear at 9+00 left.
		M60–41	Measured rut depths only on undamaged portion of the product. Ruts are 2 ft deeper on the "plain soil." In excess of 19 in. of thaw in the rut at the tire-chips/geonet transition.
	HEMTT: 10.5/8.5		Vehicle is riding in left rut made by tank, but to the left of the right rut made by the tank.
		HEMTT–2	Ruts deeper than those over the geonet and tire chips are forming at the transition between the sections.
		HEMTT–20	
		HEMTT–25	HEMTT has made two sets of ruts—one of them has one rut on the outside of the left edge of the geonet—the other has one on the outside of the right edge of the geonet. Dozer drove on it—minor additional damage. Ripped up north edge of the material.
		HEMTT–26	HEMTT rides to the right in both directions.
		HEMTT–28	
		HEMTT–all	
Sta. 9+00-9+50 (Tire chips)	M60: 20/11		Left rut depth is partly due to large "water hole" on left side of this test section.
		M60–10	Tire chips are being pushed into the water hole that exists on the left side of this section.
	HEMTT: 17/9		In excess of 19 in. of thaw in the rut at the transition to the DS geonet.
		HEMTT–25	Trail is falling into the water hole adjacent to it.
		HEMTT–29	Standing water in the right rut (next to the ponded area).
Sta. 9+50-10+00 (Tire chips w/geotextile)	M60: 15/9.5		Excavated trench across the geotextile, and it measured only 7.5 ft across—it was not present in either of the ruts made by the tank. East rut was formed off of the test section—it was the deepest. Left rut is widening.
		M60–10	5.5 in. to in excess of 24 in. of thaw in the ruts at 10+00.
	HEMTT: 8/7		

Table E3 (cont'd). Observations of test section performance made during trafficking on the wooded trail.

Test section	*Rut depths after trafficking (left/right)*	*No. of passes*	*Comments/ observations*
Sta. 10+00-10+50 (slash)	M60: 7/7		Difficult for troops to walk on. Mud mounded up in between the tank tracks. Slash in the ruts was broken.
		M60–first few	Tank slowed down for this section until the slash was sufficiently flattened.
	HEMTT: 10/6		5.5 in. to in excess of 24 in. of thaw in the ruts at 10+00.
		HEMTT–all	HEMTT slowed while driving over the slash.
Sta. 10+50-11+00 (slash w/geotextile)	M60: 7/8		No different from slash without geotextile. Thaw depth in right rut is about 0.8 ft. There is a 20-in. rut at the chunk-wood-slash transition.
		M60–first few	Tank slowed down for this section until the slash was sufficiently flattened.
	HEMTT: 7/6		
		HEMTT–all	HEMTT slowed while driving over the slash.
Sta. 10+75-11+75 (chunkwood)	M60: 12/17		Surface water exists on both side of the trail in this location. Test section "spread" laterally considerably.
	HEMTT: 7.5/6		7 to 11 in. of thaw in ruts at 11+00.
		HEMTT–all	Driver varied travel paths.
Sta. 11+75-12+25 (chunkwood)	M60: 19/16		Surface water exists on both side of the trail in this location. Rutted to the frost. 3 to 5 in. of thaw in ruts at 12+00.
	HEMTT: 12/15		
			Driver stayed to the right in both directions.
		HEMTT–all	
Sta. 13+75-14+75 (wood mats)	M60: 7/7		Mats probably perform the best when placed on a level surface. There is dozer and tank damage in about 30% of the boards (occurs between the stringers). About 10% of the east side edge pieces are chewed and slivered. There are also about 5 in. ruts where the tank sometimes traveled off the mats. Thaw depth is 0.4 to 0.7 ft. Mats slid on the soil and buckled somewhat during trafficking. 4.5 to 5.5 in. of thaw in ruts at 14+00.
		M60–all	
	HEMTT:		
Sta. 14+75-15+50 (control with chunkwood)	M60: 11/11		Chunkwood acted "spongy"—compressed as tank passed over it then rebounded. 8 in. of thaw in ruts at 15+00.
	HEMTT: 16/19		
Sta. 15+50-16+50 (chunkwood)	M60: 20/20 HEMTT: 6/12		Thaw depth in the rut is 6 in., 5 in. of thaw on east side of trail, unfrozen on the west side.
Sta. 16+50-17+75 (chunkwood with TS 1000)	M60:		Standing water is present at a bend in the trail.
	HEMTT: 13/10		6 in. of thaw on the west side of the trail at 17+00.
		HEMTT–25	Geotextile showing through the chunkwood at stations 17+00 to 17+15.
Sta. 18+00	HEMTT: not measured		Thaw depths are 12 to 18 in. in the ruts.

Table E4. Observations of test section performance made during and after trafficking on the pentagonal loop trail.

Test section	*Rut depths after trafficking (left/right)*	*No. of passes*	*Comments/observations*
Chunkwood	24.5/15.5		Road spread about 4 ft during trafficking. In-situ soil is exposed on the inside rut and slightly exposed on the outside rut.
		all	Woodchunks ride up on inside track (of tank).
		10	Inside corner is below original soil surface.
		30	Tank bottomed out on rest of passes.
Tire chips	18/16.5		Road spread about 4 ft during trafficking. The tire chips are mixed in with chunk-wood and soil. The wood chunks were carried forward by the tank onto this test area. Tire chips getting into the tank track.
		4+	
Slash	24/14		Tank pushed slash into the ground. Very little slash is left on the inside rut. The out-side rut andthe flat have slash left. The tank obviously bellied out in this area. Original soil surface is exposed on inside path.
		10	
Tire mats	not app.		Mats were completely displaced during trafficking. Some metal ties are broken and tires were cut by the broken wires. Some tires are cracked, and at least three mats lie perpendicular to the trail.
		18	Mat became lodged in the fender.
		all	Many wires were broken and posed a hazard to the tank track.
Polyrock w/gravel	32/25		Material is badly torn on the inside rut, but it is intact in the outside rut. In-situ soil is obviously excavated on the inside rut. Road spread at least 2 ft during trafficking Polyrock was exposed on inside corner.
		10	Belly of the tank is compacting the soil.
		29	Gravel is moving from inside to outside of corner.
		all	

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APPENDIX F: MISSION STATEMENT TO THE WISCONSIN NATIONAL GUARD

Wisconsin National Guard Mission Statement
TEST AND EVALUATION PLAN FOR
RAPID STABILIZATION OF THAWING SOILS
Cold Regions Research and Engineering Laboratory (CRREL)

Presented to the Wisconsin National Guard

MISSION

In partnership with Wisconsin National Guard, Fort McCoy and the USDA Forest Service, CRREL is conducting a test and evaluation of several expedient stabilization techniques for building temporary roads and trails on thawing soil for the U.S. Army. Test sections will be constructed at three different locations: a wooded trail, 12% slope, and level curves. After each test area is completed, the sections will be trafficked and evaluated.

The Wisconsin National Guard Unit will construct and evaluate these test sections using the guidance provided below and by CRREL personnel on-site. An overview of the test and evaluation scheduling is given in Figure F1. A briefing will be held at the site on March 16 to provide any necessary training, answer questions and go over details and last minute changes.

PRETESTS (March 16)

Prior to building the test sections, pretests will be conducted on two techniques. A small rubber tired vehicle will traverse 50 passes on a small section of the tire chips to determine if tire punctures will be a problem. **The tire chip pretest will require a loader, a pick-up truck and one assistant. The test will occur where the tire chips are stockpiled.** The other pretest will consist of driving a tank on several different geosynthetics about 50 ft long to see if they can withstand the aggressive tank track during turning. National Guard (NG) support is required for both of these tests. **The geosynthetic pretest will require three laborers and a 4-wheel-drive vehicle, preferable a pick-up truck.** Ft. McCoy will provide a tank and driver.

TEST SECTIONS

Test sections should be approximately 12 to 14 feet wide and range in length from 50 to 150 feet long (additional length can be added to fill in remaining holes so that the entire road is traffickable). The following test sections will be constructed:

1. **Chunkwood,** 8 in. thick,
   a) with added sand,
   b) without added sand
2. **Chunkwood,** 16 in. thick,
   a) with added sand,
   b) without added sand
3. **Tire chips** 12 in. thick

Personnel:

Karen Henry—staker, water content (w.c.) collector, note taker, evaluation form	I NG Person
Jeff Stark—Clegg impact device and cone penetrometer operator	I (3) NG Person
Karen Geary or Army School Staffer—dual cone penetrometer operator	I NG Person
Maureen Kestler—thaw depth temperature gauge, and profilometer operator	3 NG person
Vitel moisture meter, densities	2 NG
Sally Shoop—Field Chief	

Materials:

wooden stakes (150) and metal pins (in case the ground is too frozen for the stakes)
moisture content tins
plastic reusable bags
markers: sharp and wide tip for marking stakes
surveyors flagging
marking paint
field book
film

Equipment:

rule or rod for measuring thaw depth
backpacks or cart for hauling w.c. samples
Clegg impact device
Cone penetrometer
thaw depth temperature probe
surveyor's tape, 2–100 ft and 300 ft
level
tripod
rod
profilometers
balance for moisture content
oven to dry moisture samples
Vitel Hydra Logger
Vitel probes
tape measure 25 ft (2 or 3)
computers (2)
still camera
rut profiler
drive cylinder
drive cylinder hammer

To document:

rut profiles—at every 50-ft station
surface roughness—estimate for every 50-ft section (according to CRREL SR 87-15)
vegetation (estimate percentage of ground surface covered) standing water (depth)
video tape each test section prior to construction
photograph of each test section prior to construction—document photo number and test section in notes.

Schedule:

The site characterization will be carried out on 17 March 1995, and on the day prior to the beginning of construction of the other test sections. The sites will be staked by CRREL; staking on the 15th or 16th will give us a chance to see exactly where the test sections will go and if any changes need to be made. The NG can probably survey the site before construction.

Other Notes:

Be sure to match the 50-ft stakes to the test sections to be constructed (if possible).

Figure F1. Overview of test and evaluation scheduling.

   a) with a geotextile separator 12 in. thick
   b) without a geotextile separator 12 in. thick
4. **Debris/slash** approximately 12 in. thick when compressed
   a) with a geotextile separator 12 in. thick
   b) without a geotextile separator 12 in. thick
5. **Terra Mats tire mats**
   a) **CM 420** tire mats
   b) **TMC 410-12** tire mats
6. **Wood mats**
7. **Double sided geonet** or geocomposite (selected in pretest)
8. **Geosynthetic geogrid** or geocomposite (selected in pretest)
9. **PVC fascine** with a wood mat travel surface
10. **Control** bare ground with no treatment

SITE CHARACTERIZATION

The subgrade soil and surface features of test sites will be characterized prior to construction. In addition to visual observations the following measurements will be made:

- Moisture content determination (gravimetric)
- Moisture content determination (volumetric) —Vitel Hydralogger
- Clegg impact device
- Cone penetrometer
- Thaw depth
- Soil temperature
- Profilometer readings
- Level survey.

CRREL and Army School staff will conduct these tests with assistance from National Guard personnel. **Six National Guard personnel are required.**

CONSTRUCTION

The test sections have been arranged to keep sections that are constructed in a similar manner together. The wood mats, Terra Mats, geosynthetic and PVC pipe fascine test sections will require the placing of materials by a forklift or see (loader/backhoe). These materials can be transported to the test sites on a lowboy trailer. The chunkwood, tire chips and debris/slash test section will require material be hauled from the staging area in dump trucks and spread by bulldozer. The debris/slash will probably be placed by hand. The approximate volume of material for each test section is 15 to 35 cubic yards. **The required equipment and manpower to construct the test sections will be determined by the National Guard.**

Guidelines for constructing the test sections follows:

Chunkwood: The chunkwood will be stockpiled at a site approximately 1.5 miles from the wooded trail and 2.5 miles from the slope section. Chunkwood will be trucked to the test site and spread with a bulldozer.

Chunkwood/sand mix: The chunkwood and sand will be mixed when the dump trucks are loaded. The mixing process is accomplished by placing 3 scoops of chunkwood in the truck followed by 1 scoop of sand.

Tire Chips: The tire chips will be stockpiled and trucked to the test sites. A bulldozer will be used to spread the tire chips.

Tire Chips with a geotextile separator: The tire chips will be stockpiled and trucked to the test sites. Prior to dumping the tire chips, a geotextile will be placed on the subgrade by hand (also see section on Construction Guidance—geosynthetics). A bulldozer will be used to spread the tire chips.

Debris/Slash: The debris/slash will be stockpiled and trucked to the test section by dump truck or another means chosen by the National Guard. The debris/slash will be placed and matted down by construction equipment to form a compact and uniform layer. The maximum log size allowed is 8 in. diameter.

Debris/Slash with geotextile separator: Prior to placing the debris/slash as directed above, a geotextile separator will be placed on the subgrade by hand (also see section on Construction Guidance—geosynthetics).

Terra Mat CM 420: These are truck tire sidewalls that are fastened together to form a tire mat 20 ft long and 5 ft, 3 in. wide. A mat is placed in each wheel track. The mats weigh approximately 1,100 lb each. The mats will be placed by a SEE (loader/backhoe).

Terra Mat TMC 410: These are truck tire sidewalls and tread that fastened together to form a tire mat 10 ft long and 5 ft wide. The mats weigh approximately 1100 lb each. A mat is placed in each wheel track. The mats will be placed by a SEE (loader/back hoe).

Wooden mats: ***The wooden mats will be constructed by the National Guard on 17 March.*** Materials will be stock piled at Ft. McCoy. Approximately 200 feet of mats are required. Detailed construction procedures will be provided at the briefing on 16 March.

Double-sided geonet: This is a three-dimensional geonet (an HDPE mesh) sandwiched between two needle-punched geotextiles. The material comes in rolls 12 ft wide and between 150 and 300 ft long.

Geosynthetic geogrid: A planar synthetic, such as HDPE, with relatively large apertures (e.g., 1–3 in. square), made to reinforce weak soils. The material comes in rolls 12 ft wide and between 150 and 300 ft long.

PVC Pipe Fascine: ***The PVC pipe fascine will be constructed by the National Guard on 17 March.*** The fascine is constructed by connecting 3 and 4 in. PVC pipe together using 3/16 in. steel cable. One section is approximately 8 ft long. Detailed construction procedures will be provided at the briefing on 16 March. Materials will be stockpiled at Ft. McCoy.

CONSTRUCTION GUIDANCE—GEOSYNTHETICS

Storage

The geosynthetics should be kept in protective plastic, indoors, until they are transported to the test site.

Handling and transport

The geosynthetics should be handled carefully, so as not to damage the products prior to testing. The use of forklifts for loading and unloading the products is recommended.

Construction

All sections

1. Woody vegetation should be cleared as square as possible at the ground surface. Roots and stumps do not need to be removed.

2. The geosynthetic should be rolled, by hand, in line with the trail centerline in one continuous sheet. This is best accomplished with two people, one on each edge.
3. The geosynthetic should not be dragged across the subgrade surface.
4. Wrinkles and folds should be removed by stretching as required.
5. Overlapping is not recommended for these tests. However, if it is necessary, a 1-m (3-ft) overlap is recommended and the previous roll should be on top.
6. For curves, the geosynthetic should be folded and overlapped in the direction of the turn (previous fabric on top).

Sections utilizing a geotextile separator

7. Before covering with material, the geotextile should be inspected for holes, rips, and tears. If any occur, Karen Henry should be contacted in order to make a decision about whether to replace, repair or proceed with no repairs.
8. The chunkwood, tire chips or slash should be end-dumped onto the geotextile from the edges of it or from the previously placed material.
9. Lift thicknesses will be the same as those sections without the geotextile. (If the soil is supersaturated, it may be necessary to limit the height of the pile dumped in order to avoid failure of the subgrade.) At no time should the lift thickness be thinner than the design lift thickness; thus, the lifts should be graded down from a pile dumped near the edge or from a previously placed lift.
10. If, after trafficking, grading is required due to excessive rutting, new material should be added to the ruts in order to avoid damage to the geotextile separator.

Bare geosynthetic sections

11. If *problematic ruts* form in the test section during construction (or trafficking), the ruts (only) should be filled with fill that is available and deemed suitable. In addition to filling in the ruts, this will help the material resist further deformation into the ruts. Possibilities for fill include chunkwood, logs, aggregate or tire chips. Alternatively, the material could be staked approximately every meter (2–3 ft) near the edges if the thaw depth is not too shallow. However, this is not the "first choice" since the material will be damaged by driving stakes through it, and this will increase the chances of rips and tears propagating at these locations.

WOODED TRAIL

For the wooded trail, the test sections will be laid out as shown in Figure F2. Two construction crews can work simultaneously building toward the center area containing the control test areas (one wet and one dry). The control areas should not be trafficked or disturbed during the construction phase. The 3 wet areas on the south end of the road are in a clearing and therefore these can be driven around during construction in the woods to alleviate undue disturbance prior to trafficking.

SLOPES

The test sections will be laid out as in Figure F3. **The road grade should be made as uniform as possible prior to building the test sections**. This may involve grading or bulldozing to cut high spots and fill low areas.

The test sections will be constructed in a similar manner as the test sections in

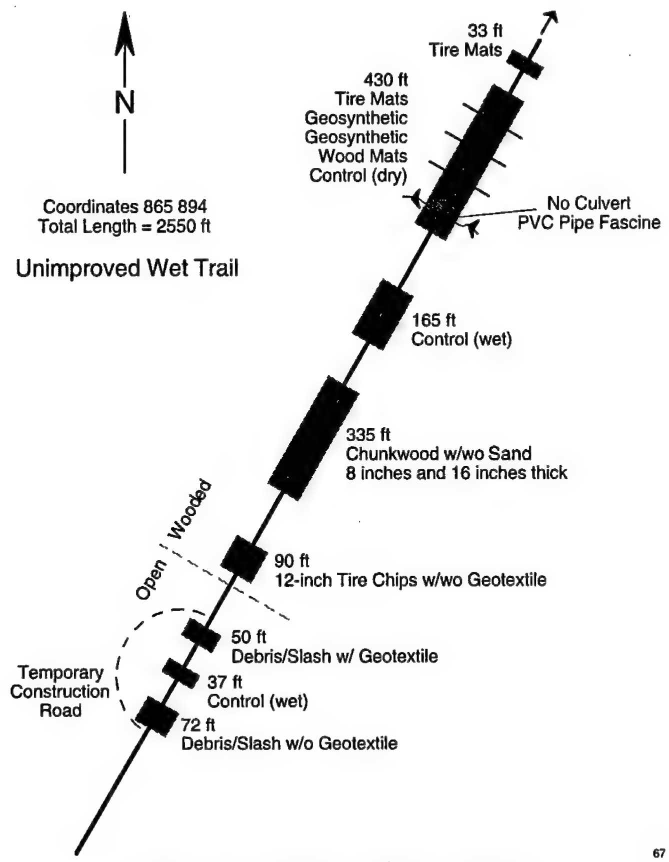

Figure F2. Wooded trail test sections.

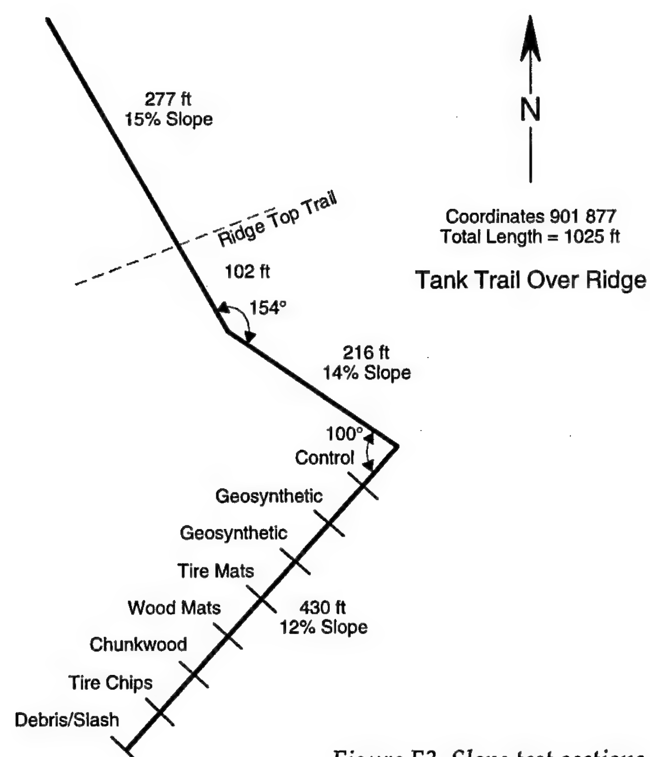

Figure F3. Slope test sections

the woods. However, construction vehicles will be allowed to travel on unstabilized trails. Any construction "trick" learned from the wooded trail should be used when building these test sections.

CORNERS

The construction and performance of 5 of the test sections will be evaluated by building a pentagonal test section of 100-ft sides with the test sections centered on the corners as shown in Figure F4.

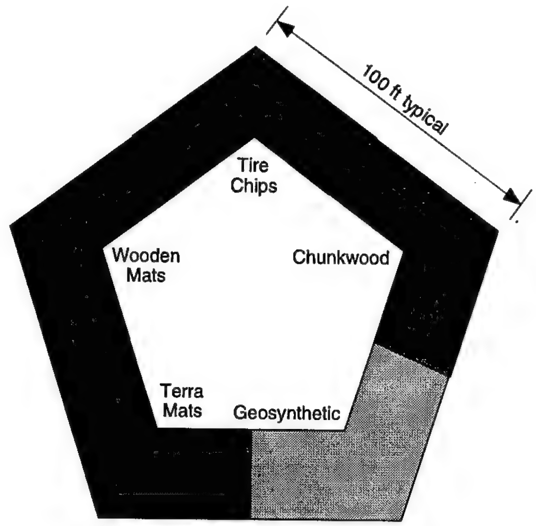

Figure F4. Corners test section.

CONSTRUCTION EVALUATION

Construction of each of the test sections must be evaluated according to the evaluation form provided at the site. As we are trying to assess the suitability of these materials for the Army, be sure to include the National Guard evaluator's opinion and comments pertaining to the suitability.

PERFORMANCE TESTING

ALL AREAS

After all test sections in an area have been built, the test road will be traversed by a single pass of a pickup truck or similar utility vehicle. Then each of the test sections will be trafficked 50 passes with a M1 and then 50 passes with a HEMTT—both fully loaded. The M1 and driver will be provided by Fort McCoy (via Kerkman). The National Guard unit will provide the HEMTT with driver. The HEMTT tire pressure should be set as follows: axles 1 and 2 at 20 psi, and axles 3 and 4 at 30 psi. If the ground is frozen, the tire pressures should be axles 1 and 2 at 35 psi, and axles 3 and 4 at 40 psi. The drivers should be aware of the vehicle performance and differences among the test sections and will complete evaluation forms. The driver should try to keep a constant vehicle speed over all the test sections (10 to 20 mph), which will be recorded on the evaluation form along with any speed variation caused by the different test surfaces or deterioration of the test surfaces. At the end of the M1 and HEMTT trafficking a small utility vehicle will again traverse the test sections.

Possible delays during this stage include flat tires and vehicles getting stuck.

SLOPES

The slopes will also include a test of the vehicles starting from a stop.

PERFORMANCE EVALUATION

The performance of vehicles and test sections will be evaluated after 1, 10, 25 and 50 passes of each vehicle. Each test section is evaluated separately; therefore, we will need 10 National Guard evaluators at the wooded trail, 8 at the slopes and 5 at the corners. Karen Henry or another CRREL representative will be present for support during the evaluation.

Aside from the self-explanatory notations on the evaluation form, the rut depths and test section expansion must also be measured after 1, 10, 25, and 50 passes.

Rut depth

Intermediate rut depths can be measured by laying a straight rod or level across the rut and measuring the distance from the rod to the bottom of the rut. Final rut depths will be more thoroughly characterized by measuring the road profile using the profilometer (Fig. F5). CRREL will provide two profilometers which must be shared by the evaluators (one person can call the depth while the other records data).

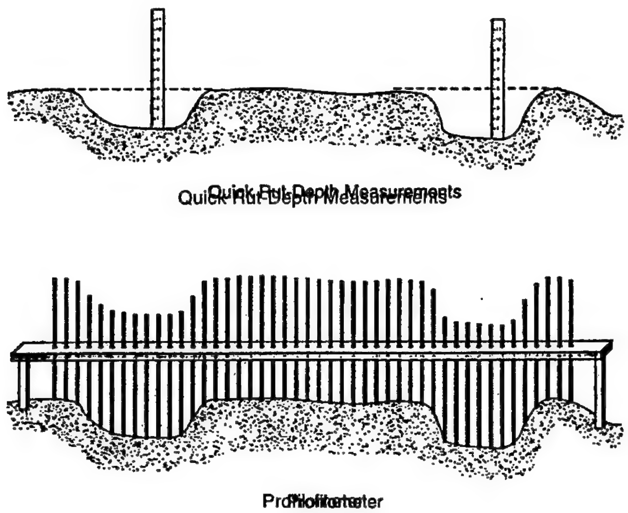

Figure F5. Rut-depth measurements.

Lateral expansion

Each of the test sections will be staked on the sides prior to testing. The distance across the test section, measured at these stakes will be recorded at 1,10, 25 and 50 passes of each vehicle (Fig. F6).

After ALL trafficking tests have been completed, every test section that utilized a geotextile separator should be carefully excavated so that a 2 m by 1 m (approximate size) sample can be cut from the material. This should also be done for any geosynthetic material that was anchored by placing fill (chunkwood, logs, slash, gravel, etc.) into ruts. The purpose of the excavation is to be able to visually inspect the material for damage. A representative from CRREL will be present to indicate where the excavation should occur, observe excavation and take the sample. It is important that the material not be damaged by the backhoe during excavation. One backhoe or other excavation equipment and operator, and two laborers will be required for this task.

In addition to the evaluation measurements and observations, the construction and performance with be recorded on video by CRREL and others.

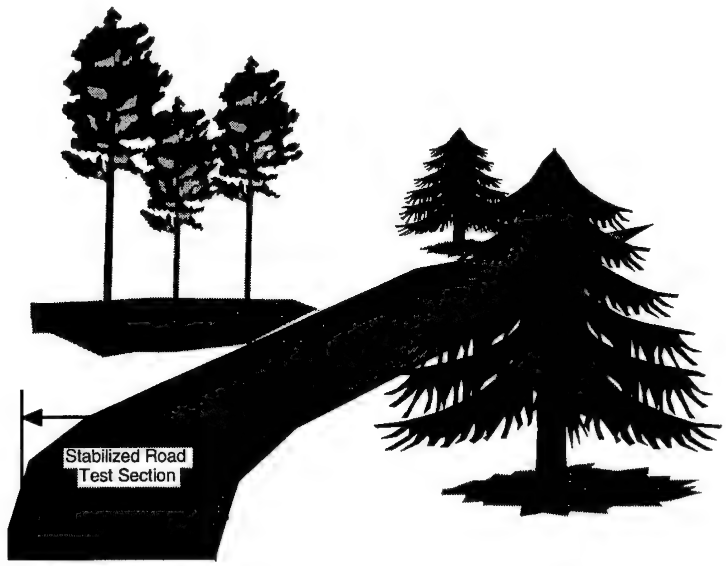

Figure F6. Lateral expansion of test section.

SITE CLEANUP AND REMOVAL OF PORTABLE SECTIONS

Site cleanup will involve removal of the following test section materials; Terra Mats and wooden mats. The debris/slash, tire chips and the geosynthetic may have to be removed. The Terra mats will be cleaned and prepared for shipping. Jim Kerkman will determine if the wooden mats will be cleaned and stored for future use or disposed of. If the other materials are removed, they will be disposed of in a manner that is specified by Jim Kerkman.

AFTER ACTION REPORT

Should include

- Site Characterization
- Construction Evaluation
- Performance Testing Evaluation
- Weather Data from Fort McCoy for the Month of March

Task	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Travel to Sparta	XX																	
Site tour -		XX																
last minute changes with Kerkman		XX																
National Guard briefing/training			XX															
Geosynthetic pre-test			XX															
Tire chip pre-test			XX															
Build wooden mats				XX														
Build PVD pipe facine				XX														
Site characterization - wooded trail				XX														
Construction - woods trail					XX	XX												
Tests and evaluation - woods trail							XX	XX										
Characterization - slopes						XX												
Construction - slopes							XX	XX										
Test and evaluation - slopes									XX	XX								
Remove mats for use on corners									XX									
Characterization - corners								XX										
Construction - corners									XX	XX								
Test and evaluation - corners											XX	XX						
Site cleanup, section removal, shipping											XX	XX	XX	XX	XX	XX		
We will likely work in three crews:																		
Site chararacterization - Jeff as CRREL Representative																		
Construction - Maureen/Jeff as CRREL Representatives																		
Performance evaluation - Karen as CRREL Representative																		
Sally/Jim will roam and act as go-for, put out fires, etc.																		

Figure F7. Proposed schedule.

PERFORMANCE EVALUATION

Date	*HEMTT Tire pres.*			*Test section type*	*Test area*
Observer:	Front	L	R	chunkwood	wooded road
HEMTT Driver:		L	R	tire chips	slopes
Experience (yr)		L	R	tire mat	corners
Vehicle condition:	Rear	L	R	wood mats	other
Maintenance current?				slash	
M1 Driver:				PVC fascine	
Experience (yr)				geosynthetic	
Vehicle condition:				other	
Maintenance current?					

Driver/Observer Survey

	M1					*HEMTT*				
	pickup truck	1 pass	10 passes	25 passes	50 passes	1 pass	10 passes	25 passes	50 passes	pickup truck
Slipping or traction loss										
Material interference w/ vehicle										
Vehicle handling										
Vehicle speed										
Mat'l response to vehicle load (No. holes, breaks)										
Adjustments, repairs?										
Lateral dimension										
Rut depth										
Profilometer	—	—	—	—	YES	—	—	—	YES	—
Comments										

Figure F8. Performance evaluation sheet.

Construction Evaluation Form

Rapid Stabilization of Thawing Soils Project

Ft. McCoy, Wisconsin, 14–31 March

Evaluator ____________________ Date ____________________

Location of Test Section
Wooded Road ____
Slopes ____
Corners ____
Other

Type of Test Section
Chunkwood _____ with geosynthetic Y N
Tire Chunks _____ with geosynthetic Y N
Debris/Slash _____ with geosynthetic Y N
Wooden Mats _____
Terra Mats _____ Tire Side Walls 20 ft
Terra Mats _____ Track Vehicle 10 ft
PVC Pipe Fascine _____
Geosynthetic Composite _____

Equipment Required

	Yes	No	Quantify
D7 Bulldozer	Yes	No	
Dump Truck 7 yd	Yes	No	
Grader	Yes	No	
Loader	Yes	No	
Backhoe	Yes	No	
Fork Lift	Yes	No	
Lowboy Trailer	Yes	No	

Personnel Required

Started Construction ______________ Ended Construction ______________

Please note any major breaks in construction

Volume of material used (# of truck loads) 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19

How difficult was construction?

Ways to improve construction?

Methods that worked well?

Comments:

—Figure F9. Construction evaluation form.

RAPID STABILIZATION OF THAWING SOILS
FT. MCCOY, WI MARCH 1995
SITE CHARACTERIZATION

Observers:____

Date/time:____

Trail: wooded slope corners

Test Section:____________________ **Station:**__________ **to** __________

Ground conditions (frozen, wet, dry, snow, etc.):____________________

____

Weather conditions: Temperature: __________ **Wind:** ________________

Sun: ________________ **General:** ________________

____

Standing water: none <10% 10–25% 25–50% 50–75% >75%

Depth of water: Maximum ______________ Average ________________

Area vegetated: <10% 10–25% 25–50% 50–75% >75%

Flowing water (location, direction of flow, width and depth of stream):

____

____

Cross section (indicate which lengths of test section are in each category):

trail is crowned or flat	bowl-shaped < 1 ft between side and CL	bowl-shaped, 1–3 ft between side and CL	bowl-shaped, > 3 ft between side and CL

Corrugations (indicate percentage of surface area covered in each category):

no corrugations	< 2" (5 cm) deep	2–5" (5–13 cm) deep	> 5" (13 cm) deep

Figure F10. Site characterization.

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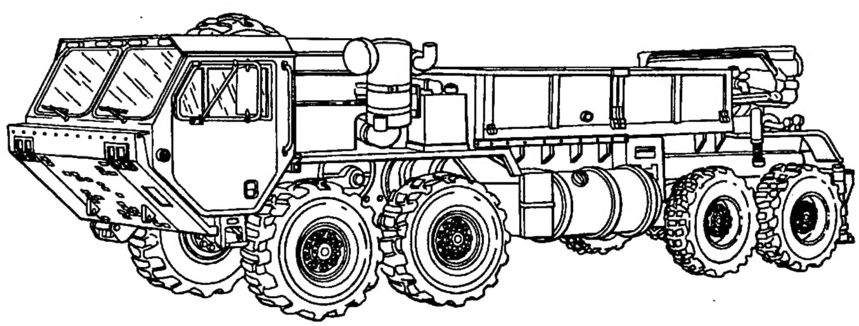
APPENDIX G: VEHICLES USED IN TEST PROGRAM

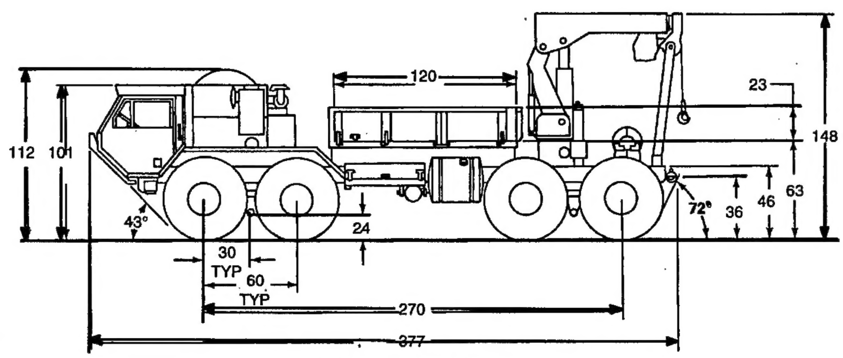
Specifications for the M60A3 Tank	
Crew	4
Combat weight	51,500 kg
Unloaded weight	47,500 kg
Power-to-weight ratio	14.56 bhp/tonne
Ground pressure	0.85 kg/cm²
Length gun forwards	9.436 m
Length hull	6.946 m
Width	3.631 m
Height	3.27 m
Firing height	2.095 m
Ground clearance	0.45 m
Track	2.921 m
Track width	711 mm
Track adjustment	Hydraulic
Track type	T142 replaceable pads
Length of track on ground	4.235 m
Max road speed	48.28 km/h
Fuel capacity	1420 liters
Max road range	480 km
Fording	1.22 m
Fording with preparation	2.4 m
Gradient	60%
Side slope	30%
Vertical obstacle	0.914 m
Trench	2.59 m
Engine	AVDS-1790-2D
Suspension	Torsion bar

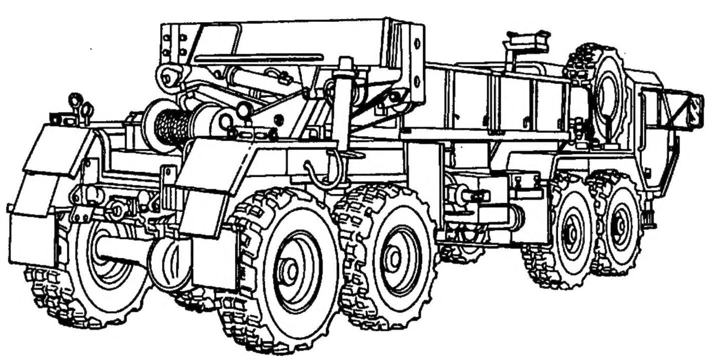
a. M60A1 Tank.

Figure G1. Vehicles used for trafficking Fort McCoy test sections.

Specifications for the M984 Wrecker Truck		
General Information	**Performance data**	**Vehicle data**
Nomenclature: 10 ton, recovery, 8×8,	Fording: w/kit:	Type classification and date: Std A, 1980
HEMTT, w/winch	wo/kit: 48 in.	Replaces/replaced by: Augments Goer
Model number: M984	Approach angle: 43 degrees	Life Expectancy: 20 years
Crew/cab capacity: 2	Departure angle: 62 degrees	Payload: 31,000 lb
NSN: 2320-01-097-0248	Cruising range: 300 mi	Towed load allowance: 20,000 lb
LIN: T63093	Maximum:	Air transportability: C5, C141, & C130 aircraft
SSN: D162030	Sustained forward speed (@ 2,100 rpm)	
TM: 9-2320-279-Series	4th Gear: 57 mph	**Equipment options**
	3rd Gear: 41 mph	Kits: Arctic, alternator, GPFU, radio, M8 alarm
Characteristics	2nd Gear: 28 mph	machine gun
Horsepower: 445 bhp @ 2,100 rpm	1st Gear: 15 mph	Winch: Self recovery
Transmission: Automatic; Allison 740-HD	Speed on 3 percent grade: 40 mph	
Electrical system: 24 V, 12 pin	30 percent grade: 5 mph	**Shipping data**
Tires: Michelin 16:00 × R20XL	Grade: Side slope w/adequate tractive	Weight: 41,574 lb
Brakes: Air, 16.5× 5F, 16.5 × 7R	Surface: 30%	Cube: 2,340 cu ft
Blackout lights: Yes	Towed speed (ref. FM 20-22): 15 mph	Ground clearance: 24 in.







b. M984E1 wrecker/recovery HEMTT.

Figure 26 (cont'd). Vehicles used for trafficking Fort McCoy test sections.

APPENDIX H: CONDITIONS ASSOCIATED WITH NOGO SITUATIONS ON THE WOODED TRAIL.

	12+75 to 13+75	*14+75 to 15+50*	*16+50 to 17+75*	*7+00 to 8+20*	*2+50 to 3+50*
Date of NOGO	3/17	3/21 or 22	3/21 or 22	3/26	3/26
Number of passes	2	20	20	15	25
vehicle	M60A3	5-ton dump truck	5-ton dump truck	HEMTT	HEMTT
Nature of surface	prior to test section construction	control	TS1000 geosynthetic on soil surface	control	control
Thaw depth (in.)	10.9	8.4	11.8	6.3	12.3
Water content (%)	18.2	20.0	17.0	22.0	14.5
CI (0–6)	62	73	60	17	113
CI (6–12)	281	252	244	294	
240 CI (12–18)	300	300	300	300	300
Clegg CBR	1.2	0.3	1.1	4.0	2.6
DCP CBR	7.8	6.8	5.24	7.5	5.3
Dry density kg/m^3 (pcf)	1754 (109.1)	1775 (110.4)	1796 (111.7)	—	—